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Physical Activity and Test Anxiety

Joshua Edwards

Test anxiety, especially in mathematics, has been a concern for teachers, students, and parents for decades. The recent policies that require high-stakes tests at nearly every grade level after primary school has added to these concerns. Preparation for tests through effective teaching that leads to solid student understanding of mathematical concepts and procedures can reduce anxiety. However, many students experience test anxiety no matter how well they are prepared.Physical activity is a method that may provide a viable means to address test anxiety and stress.

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Prior research has established that teachers' use of curriculum materials is affected by a range of factors, such as teachers' conceptions of mathematics teaching, and the nature and extent of their teaching experience. What is less clear, and far less examined, in prior research is the role that the teacher guide (TG) may play in mediating the influence of these and other factors on teachers' decisions and actions. Accordingly, this study examines how two 6th grade teachers use the TG from Connected Mathematics Project as a resource in making planning and enactment decisions, and factors associated with patterns of TG use. Through cross-case analysis, the author found that these teachers seemed to draw largely from their previous experiences and their own conceptions of mathematics teaching and learning when making planning and enactment decisions related to mathematical tasks, and not particularly from the TG.

Community-Based Service-Learning as a Source of Personal Self-Efficacy: Preparing Preservice Elementary Teachers to Teach Science for Diversity

Neporcha Cone

Bandura (1997) contends that when compared to other sources of efficacy, mastery experiences, when presented appropriately, have the most powerful influence on self-efficacy. The purpose of this study was to investigate the effects of community-based service learning (CBSL) experiences on preservice elementary teachers' personal self-efficacy beliefs about equitable science teaching and learning. Data were collected using pretests-posttests and post-questionnaires with the study sample. Findings from this study support Bandura's assertion. CBSL experiences were an important source of personal self-efficacy and significantly influenced preservice elementary teachers' personal self-efficacy beliefs about equitable science teaching and learning.

Connecting Science and Mathematics: Using Inquiry Investigations to Learn About Data Collection, Analysis, and Display

Judith Morrison, Amy Roth McDuffie

The purpose of this study was to explore the effect of providing preservice teachers the opportunity to collect real data in a science methods inquiry investigation and using the data, design data displays in their mathematics methods course. The research questions focused on how preservice teachers' understandings of data displays, research design, and the specific content addressed improved when they used these displays to attempt to communicate the data they had collected themselves in their inquiry investigations. The findings show that by creating and scrutinizing their data displays, the preservice teachers were able to recognize the limitations of their inquiry investigation design.

Middle School Students' Conceptual Learning from the Implementation of a New NSF Supported Curriculum: Interactions in Physical Science™

Charles J. Eick, Michael Dias, and Nancy R. Cook Smith

A new National Science Foundation supported curriculum, *Interactions in Physical Science*™, was evaluated on students' conceptual change in the twelve concept areas of the national physical science content standard (B) for grades 5-8. Eighth grade students (N=66) were evaluated pre and post on a 31-item multiple-choice test of conceptual understanding developed by the Harvard –Smithsonian Center for Astrophysics. Significant student gains ($p<.05$, t-test, two-tailed) occurred in all concept areas in the category of **properties and changes in properties of matter;**

for the force concept areas in the category **motions and forces;** and for the heat transfer and light interactions areas in the category of **transfer of energy.** Two of the six concept areas in the category of **transfer of energy,** chemical and nuclear reactions and the sun as a major source of energy, were not addressed in this study. Significant learning gains as item percent correct were typically close to 20%, though effect sizes were small to medium in magnitude (d = 0.3-0.6). Implications of the study for conceptual change curriculum and teaching are discussed.

Research in the Classroom

Student Learning about Twelve Features of the Nature of Science

Robert Yager

Five Teacher Leaders organized a study regarding two of their sections of 8-9th grade science. One section was the experimental section where twelve constituents of the Nature of Science (NOS) were used as an added consideration to activities, discussions, projects, and focus for all aspects of science content. The control section was a typical one where STS approaches were used without any conscientious efforts to add appropriate NOS considerations. Significant differences were found regarding student improvement and understanding of the twelve NOS constructs that were utilized; no such differences were noted in the control sections for the five teachers.

editorial

Gerald Kulm, *Texas A&M University*

A Time of Change

As a new year and a new volume of this Journal begins, it is difficult not to reflect on the many challenges we face as individuals, educators, and citizens. It truly continues to be a time of change–and whatever the future brings, it is sure to be interesting.

On a somber note, we are saddened by the passing of Dr. Wali Abdi, long-time Book Review Editor for this Journal. Although I never had the personal privilege of meeting Dr. Abdi, his dedication, longevity, and scholarship were rare qualities that we will miss. One can hope that the next generation of science and mathematics educators who will come after him and my fellow seniors will exhibit similar traits.

The Editor and SSMA Publication Committee are considering the future of the Book Review feature. The book reviewers are a dedicated group who were loyal to Dr. Abdi and who have performed a valuable service to the Journal. However, in an age of burgeoning publication of books and the availability of online reviews, one might question the value of traditional book reviews that are less timely. The Editor and Publication Committee are open to suggestions or comments on the possible continuation of the Book Review Section, or some alternative.

On the topic of change, readers should have noted that we recently added Research in the Classroom as a regular feature. One purpose of the section is to appeal to K-12 teachers, as well as teacher educators and professional development leaders. These articles are intended to reflect classroom-based studies and innovations that are grounded in research. Going beyond simple descriptions of successful lessons or teaching ideas, these articles build on and apply previous research in real settings. Outcomes and results are reflected in informal data that include anecdotal examples of effects on students. We invite manuscripts for this feature through the regular online procedure. The Editor identifies and selects manuscripts that fit the purposes and format.

The recruitment and retention of peer reviewers is an ongoing change process for the Journal. In this issue, we have listed those who have reviewed at least one manuscript this year. We express our deep appreciation for their voluntary valuable professional service to the Journal. The authors of manuscripts depend heavily on the expertise, objectivity, and timeliness of peer reviews. One notable change over the past two years has been the increase in the number of international manuscripts. At the same time, the international reviewer pool has also grown. We appreciate the willingness and efforts that our international colleagues have shown in sharing the responsibility of service in this task. As this third year of my Editorship begins, we will be purging, updating, and replenishing the reviewer list. Those reviewers who have not responded to requests to review manuscripts for the past two years will be asked if they wish to remain or be dropped from the list. We hope that the active reviewers will continue their service. As always, we welcome the application of reviewers who wish to join in this effort. A reviewer application form can be found on the web site.

One of the interesting aspects of journal Editorship is the opportunity to view the range of manuscript topics which reflect the current practice of research in science and mathematics education. Although it is difficult to see clear patterns or changes, a few do seem to emerge. As noted earlier, research has begun to look more diverse and international in flavor. In some sense, these international studies follow the trends of U. S. research, sometimes providing a chance for replication of teaching approaches or theories in very different populations. At the very least, they force us to face the idea that we may be provincial or over-confident in the strength of our literature reviews or research frameworks. In the U. S. and abroad, the topic of teacher knowledge and development continues to be a central area of research. Preservice teachers, as a convenient population, are the center of this effort making it more challenging to decide whether new knowledge is developed by the plethora of individual studies at diverse teacher preparation institutions. It does seem to be time for a careful synthesis of this work.

On the national scene, we have yet to discern the focus of the new administration in educational funding for science and mathematics education, including research. There seem to be some indications that an emphasis on teachers and teaching might be important. Certainly, there will be continued concern with the achievement gap here at home and in comparison with international peers, especially in science and mathematics. Recently, larger economic and financial problems have overshadowed the concerns of education. In the long run, however, education is a key to the solution of many of the economic issues that are emerging, including unemployment and the ability of citizens to manage their own finances with intelligence and common sense. Science and mathematics educators will have important roles to play in the coming era of change.

RESEARCH IN **brief**

Joshua Edwards
Texas A&M University

Physical Activity and Test Anxiety

Test anxiety, especially in mathematics, has been a concern for teachers, students, and parents for decades. The recent policies that require high-stakes tests at nearly every grade level after primary school has added to these concerns. Preparation for tests through effective teaching that leads to solid student understanding of mathematical concepts and procedures can reduce anxiety. However, many students experience test anxiety no matter how well they are prepared. Students often recall mathematics being taught in classrooms in which tension was created by an emphasis on timed computation drill and an emphasis on correct answers (Tobias, 1978). Ashcraft and Kirk (2001) found that math anxiety may reduce certain brain functions, possibly those that are needed most for learning mathematics. This anxiety and stress can lead to decreased performance, avoiding mathematics course taking and, eventually, to avoiding mathematics-related careers.

Physical activity is a method that may provide a viable means to address test anxiety and stress. Exercise has been shown to reduce the effect of state and trait anxiety, and can improve physical self-perceptions, and in some cases overall self-esteem, while improving an individual's mood (Fox 1999). Although consistent exercise certainly improves overall self-esteem and mood state, research also shows that exercise can have immediate effects. Analyses of subjects following a single period of exercise showed significance reductions in mood disturbance, tension, depression, anger, and confusion (McGowan, Pierce, & Jordan 1991).

Time is a precious commodity within the classroom. Any intervention to decrease test anxiety must come in a form that will pay great dividends while consuming little time. Teachers may contact their schools' physical education teachers to find creative ways to incorporate brief periods of physical activity within the classroom (Yaussi, 2005). According to the research completed by Hansen, Stevens, and Coast (2001) subjects who maintain an aerobic level of sixty percent of their maximum oxygen uptake for ten minutes will have the benefits of increased vigor while decreasing their fatigue and total negative mood state.

Stress reduction works hand in hand with self-esteem. A person who is feeling confident will be less susceptible to the drawbacks of stress. Studies with self-esteem in relation to exercise have shown interesting results. In a study conducted with children and young adults, researchers found that "...that exercise has positive short-term effects on self-esteem in children and young people. Since there are no known negative effects of exercise and many positive effects on physical health, exercise may be an important measure in improving children's self-esteem" (Ekeland, Heian, Hagen, Abbott, & Nordheim, 2004, p. 3).

As an additional benefit, physical activity can address other medical issues of concern to a large portion of our students. According to Yaussi (2005), roughly nine million young people (approximately fifteen percent) are overweight, and many of them are actually categorized as obese; while more than twenty-two percent of high school students fail to exercise on a regular basis. Children who maintain unhealthy lifestyles are at a great risk to grow into adults with severe health problems. Physical activity has a wonderful cost/effect balance as there are countless ways to perform quality physical activities that require little time or training and no financial commitment.

Physical activity has shown significant benefits in reducing stress outside of the traditional classroom environment. Physical activity, incorporated within the traditional curriculum, offers the potential for a practical and effective approach to relieving or reducing test anxiety and stress.

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The "Problem" of Experience in Mathematics Teaching

Alison Castro Superfine
University of Illinois at Chicago

Prior research has established that teachers' use of curriculum materials is affected by a range of factors, such as teachers' conceptions of mathematics teaching, and the nature and extent of their teaching experience. What is less clear, and far less examined, in prior research is the role that the teacher guide (TG) may play in mediating the influence of these and other factors on teachers' decisions and actions. Accordingly, this study examines how two 6th grade teachers use the TG from Connected Mathematics Project as a resource in making planning and enactment decisions, and factors associated with patterns of TG use. Through cross-case analysis, the author found that these teachers seemed to draw largely from their previous experiences and their own conceptions of mathematics teaching and learning when making planning and enactment decisions related to mathematical tasks, and not particularly from the TG. For example, when faced with certain planning and instructional challenges, such as students struggling with the content, teachers tended to rely on their particular conceptions of mathematics teaching to address these challenges. Despite the fact that the TG provided suggestions for teachers as to how address such challenges, it was not extensively used as a resource by the teachers in this study in their planning and enactment of lessons.

Recent reform efforts in mathematics education have influenced the development of school mathematics curricula in the United States. Although such innovative curricula have the potential to boost educational achievement while embodying new modes of instruction (Huntley, Rasmussen, Villarubi, Sangtong, & Fey, 2000; Senk & Thompson, 2003), these curricular programs place new demands on teachers and teacher learning (Trafton, Reys, & Wasman, 2001).[1] Accordingly, some curriculum developers (e.g., Lappan, Fey, Fitzgerald, Friel, & Phillips, 1998) have developed materials with the specific intent to provide teachers with the necessary pedagogical support to help students learn in ways espoused under recent reform efforts. Still, many mathematics teachers with varying amounts of experience have faced significant difficulties shaping their practice to reflect the visions of teaching and learning underlying such innovative curricula.

Given the importance of teachers' use of curriculum materials for creating learning opportunities for students (Cohen & Ball, 1990; NCTM, 2003), researchers have examined potential factors explaining the difficulties teachers have faced. Several researchers have highlighted the influential role of teachers' conceptions of and orientations toward what it means to learn and teach mathematics in the process of curriculum enactment, particularly where teachers use innovative curricula (Ben-Peretz, 1990; Cohen, Raudenbush, & Ball, 2002; Drake & Sherin, 2006; Remillard & Bryans, 2004). These findings suggest that teachers often do not blindly implement curriculum materials, but instead make decisions about what to use, how to use it, and to what end. Some researchers have also found that teachers' experiences and preferred routines can generally influence the nature of their decisions and actions in the classroom (Borko & Shavelson, 1990; Leinhardt & Greeno, 1986; Livingston & Borko, 1990). Researchers, however, have not systematically focused on the relationship between teachers' experiences and teachers' conceptions of mathematics teaching and learning, and the ways in which this relationship influences teachers' use of curriculum materials to create learning opportunities for students. Moreover, recent research examining teacher-curriculum interactions has not focused on teachers' use of a particular curricular resource, such as the teacher guide (e.g., Drake & Sherin, 2006; Remillard & Bryans, 2004). Indeed, researchers examining teachers' use of curriculum materials have recently suggested that more research is needed to understand the precise ways in which teachers' conceptions, skills, and experiences impact their use of innovative curriculum materials (Kilpatrick, Swafford, & Findell, 2001; Mathematical Sciences Education Board, 2004).

This study accordingly examines the relationship between teachers' experiences, teachers' conceptions, and their use of curriculum materials from the Connected Mathematics Project (CMP), an innovative mathematics curriculum, to create learning opportunities for students. This study particularly focuses on how such a

relationship influences teachers' use of the CMP teacher guide (TG), a curricular resource specifically aimed at supporting teachers' use of CMP to help students learn in ways espoused under recent reform efforts, to inform their planning and instructional decisions. In order to conduct such an analysis, this study presents case studies of two 6th grade mathematics teachers' use of the CMP materials, particularly the TG, during planning and instruction. In order to frame this analysis, this study brings together three important, but largely independent, strands of education research – research on the "problems" of mathematics teaching, research on the ways in which teachers' experiences can influence their decisions, and research on the ways in which teachers' orientations toward curriculum can influence their decisions. Together, this research can provide the analytical leverage needed to better understand the relationship between experience, teachers' conceptions, and teachers' use of a curricular resource specifically aimed at supporting teachers' instructional practice in the context of recent reform efforts in mathematics.

In order to examine this relationship and its implications, this study is divided into four primary parts. First, this study presents a theoretical framework based on research on the "problems" of mathematics teaching and on teachers' experience. Second, this study discusses the case study methodology employed to collect and analyze the data. Third, this study examines the CMP TG and presents case studies of how two 6th grade teachers used this resource in their planning and enactment of a unit. Fourth, this study analyzes the case studies and discusses the implications of this research for curriculum development.

Theoretical Framework

This study is grounded in the intersection between three strands of research – research on the "problems" of mathematics teaching, specifically with regard to reform-based mathematics, research on the ways in which teachers' experiences can influence their decisions, and research on the ways in which teachers' conceptions and orientations toward curriculum can influence their decisions. Lampert (1992, 2001) characterized the "problems" of mathematics teaching as the various sorts of challenges that teachers face in the course of their instructional practice. Unlike problem-based instruction that refers to teaching with mathematical tasks, "problems" of teaching refer to the work teachers do to further students' understanding of mathematics, which includes facilitating students' discussion around the content, continuously pressing students to explain their ideas and to communicate with each other, posing questions, and selecting solution strategies to present to the class that will further students' understanding.[2]

Researchers have argued that teachers need a variety of different pedagogical skills in order to successfully negotiate these types of teaching problems. For example, teachers need to be able to resist the persistent urge to simply tell and direct students how to work on the content in order to provide students with enough time to think through what they are asked to do (Donovan, Bransford, & Pellegrino, 2000). Anticipating student responses and having an awareness of common errors can also help teachers effectively respond to and redirect students' discussion (Chazan & Ball, 1999; Fennema, Franke, Carpenter, & Carey, 1993). In addition, modifying tasks, when necessary, based on students' current knowledge and ability may help teachers to be mindful of the cognitive activity in which students should be and actually are engaged (Stein, Smith, Henningsen, & Silver, 2000). As Doyle (1993) noted, "…[n]ovel or problem-centered work, in particular, appears to stretch the limits of classroom management and to intensify the complexity of the teacher's task of orchestrating classroom events" (p. 75).

This notion of problems well characterizes the types of challenges and decisions teachers face during planning and instruction when using innovative curricula such as CMP. The mode of mathematics teaching supported by such curricula is inherently uncertain, as teachers need to consider the mathematical content in the curriculum and ways to engage students in discussion about the content, while simultaneously guiding students towards a particular goal. As one researcher put it, "the conception of content is more uncertain than a traditional view of mathematics as skills and rules, the view of children as thinkers more unpredictable" (Ball, 1993, p. 394). As such, even more important than the mathematics content to students' learning opportunities is the work teachers do with the content in order to promote student understanding of the underlying ideas and concepts within the curriculum. Given these underlying ideas and concepts, teachers likely encounter several planning and instructional problems when using innovative mathematics curricula.

Experience, Teachers' Conceptions, and the Problems of Teaching Innovative Curricula

Although using innovative curricula like CMP in ac-

cordance with their underlying ideas entails certain types of problems for teachers, these problems are likely not identical for every teacher. Teachers have different characteristics and students with different needs in their classes. Such differences can help shape the problems that teachers actually face when using innovative curriculum materials during planning and instruction. In particular, some have suggested that teachers' previous experiences are problematic for teachers, especially in the context of recent reform efforts in mathematics education (e.g., Ball, 1993).

Research has pointed to experience as one potentially important factor influencing the nature of teachers' decisions and actions in the classroom. Such research suggests that experience can make teachers more effective because experienced teachers have more extensive and well-organized knowledge of both pedagogy and students, making them more flexible and attentive to the nature of students' learning opportunities they create in the classroom (Borko & Shavelson, 1990; Leinhardt & Greeno, 1986; Livingston & Borko, 1990). Experience can also directly influence curricular use – when planning, experienced teachers make more extensive mental plans than written plans and rely less on curriculum materials than their less experienced counterparts, attributing these differences to experienced teachers' extensive knowledge of pedagogy and students (Bush, 1986; Leinhardt, 1983; Livingston & Borko, 1990). As this particular notion of experience in teaching suggests, experienced teachers have spent a number of years in the classroom both establishing their planning and instructional routines and formulating (and perhaps re-formulating) their conceptions of school mathematics and what it means to learn math.

While teaching experience in general can influence teachers' planning and instruction, teachers' experience with particular curricula may influence teachers' practice as well. As teachers' experience increases in the number of years of using a particular curriculum program, they potentially become more familiar with not only the curriculum as a whole, but also with the details, nuances, and presentation of the specific mathematics content in the curriculum, and thus, may have developed routines of engaging with the curriculum in particular ways.[3] For example, teachers with experience in using a certain curriculum may be more familiar with particular questions they regularly ask students in relation to certain tasks or the different approaches students typically employ for solving different tasks. Thus, the extent of teachers' curricular experience may present certain problems for teachers.

Teachers' conceptions of mathematics teaching and learning constitute another potentially important factor influencing the nature of teachers' decisions and actions (Lloyd, 1999; Remillard, 1999; Remillard & Bryans, 2004). In fact, Lloyd and Collopy (2003) found that teachers varied in how they read and used the teacher guide, in particular, arguing that teachers' conceptions of mathematics teaching and learning played a major role in the variation of use. Moreover, the extent to which teachers' conceptions of mathematics teaching reflect the ideas about teaching and learning underlying the curriculum is equally important to consider in understanding teachers' use of curricula (Manouchehri & Goodman, 1998; Remillard & Bryans, 2004). Remillard and Bryans similarly found that teachers' particular stance towards their curriculum program influenced planning and instructional decisions, and referred to both teachers' conceptions of mathematics teaching and their curricular stance as teachers' orientation to the curriculum.

Given the ways in which experience can influence teachers' decisions and the potential effects teachers' various conceptions may have on their practice, teachers' experiences and conceptions may be bound together in important ways. As experienced teachers have spent several years in the classroom, they have likely spent considerable time establishing their conceptions of what it means to teach and learn mathematics, and a particular stance toward their curriculum program. Where such teachers do not rely heavily on curriculum materials during planning and instruction, their planning and instruction may reflect their own conceptions more than the underlying ideas of the curriculum materials. That is, in addition to serving as a valuable resource, experience may calcify teachers' conceptions and orientations to curriculum over the course of their career, and despite the underlying ideas of an innovative curriculum, teachers' pedagogical routines may include ways of using certain curricular resources that reflect teachers' own conceptions. On the other hand, the relationship between experience and conceptions may play out somewhat differently in the case of less experienced teachers. Although less experienced teachers also possess certain orientations to curriculum, such orientations may not be as powerful as in the case of more experienced teachers, as they have spent less time in the classroom formulating these orientations. Moreover, less experienced teachers may use curricula in a more prescriptive fashion, thus leav-

ing less room for their planning and instruction to reflect their orientations.

As a result of this potential relationship between teachers' experience and orientations, experienced and less experienced teachers may face different sorts of problems when using innovative curriculum materials. In addition to drawing on their experience to help them during planning and instruction, experienced teachers may face an "experience problem"–where experienced teachers who have used conventional curricula for most of their career and have developed more conventional conceptions of mathematics teaching and learning use innovative curricula, they may face challenges making decisions that comport with the underlying ideas of an innovative curriculum, even where they are presented with curricular resources that are specifically designed to help teachers overcome various problems they may encounter. Because less experienced teachers may use curricula more prescriptively, they may not face such teaching problems to the same extent. While less experienced teachers cannot draw on the benefits of experience, they also may face different (and possibly fewer) problems using innovative curriculum materials during planning and instruction.

To be sure, the discussion above does not capture many of the factors that influence teachers' planning and instructional decisions, and thus the teaching problems that teachers face on a daily basis. However, the discussion does focus on two of the arguably most important factors, their potential relationship with each other, and how these factors may influence the teaching problems that teachers encounter in the classroom. Such discussion serves as a basis for examining and analyzing the planning and instructional practices of two 6th grade teachers in the following section.

Methodology

This study presents case studies of two 6th grade teachers' use of the CMP TG. Although case studies are employed in many different research traditions that entail different epistemological assumptions (Ragin & Becker, 1992; Stake, 1995; Yin, 1994), this study was conducted using interpretive case study research that incorporates ethnographic tools such as interviews and classroom observations and some curriculum analysis in order to gather information with the intent of analyzing and eventually theorizing about the phenomenon in question. The cases presented in this article are part of a larger research study examining teachers' use of the CMP TG. The two 6th grade teachers described in this study were selected because they well illustrate the range of variation in TG use, conceptions of teaching, learning, and curriculum, experience, and thus the learning environments they created in their classrooms. Although the use of only two case studies limits the type and breadth of the conclusions drawn from the study's findings, the author selected two teachers from the larger study that clearly illustrate the inter-relationship between teachers' experience, conceptions, and curriculum use, the primary aim of the study. The addition of a third teacher from the larger study, the author argues, would not necessarily provide a more robust picture of the relationship between the three constructs.

This study was conducted in an average size, suburban school district in the Midwest, which consists of primarily white middle- to upper middle-class families. The two teachers discussed in the analysis were employed in the same school district and the same school. Despite teaching the same grade level, these two teachers had limited interactions with each other.

With regard to overall teaching experience, some research findings suggest that teachers display distinct characteristics during the "final" phase (the fifth year and beyond), in which there seems to be an increase of knowledge and ability (Burden, 1979; Feiman-Nemser, 1983). In regard to curricular experience, based on informal conversations with CMP developers and several school district personnel, three years was designated as the point in time when teachers become more comfortable and skilled with using the CMP curriculum. Thus, when originally looking at the data, the author considered teachers in this study as experienced if they had been teaching for 5 years or more and had used CMP for 3 years or more. Because teachers can have varying amounts of experience – they are not simply experienced or inexperienced, but rather have certain amounts and types of experiences – the author continually revisited the notion of experience throughout the data analysis.

Data Collection

Data reported in this article was collected between the months of October and February during the 2005-2006 academic school year. Individual interviews, classroom observations, and fieldnotes comprise the data sources for this study. At the beginning of the study and prior to the classroom observations, initial interviews were conducted with each teacher in order to obtain information about teachers' practice, their use of the TG, and their general views of CMP to inform

the case analysis. Teachers were then observed teaching an entire unit, and teaching the same class of students. Pre- and post-observation interviews were conducted with each teacher for each classroom observation. Post-hoc examinations of teachers' planning were conducted the same day of the observations in order to ensure the accuracy of teachers' responses.

Analysis of Data

Using both the interview and classroom observation data, interpretive case studies were written for each teacher (Charmaz & Mitchell, 2001; Erickson, 1985). The initial steps in writing case studies involved coding the interviews and classroom observations around teachers' use of the TG, their general stance towards CMP, and the different planning and instructional problems teachers encountered throughout the study. These codes were then used to characterize teachers' orientation towards the TG and the extent to which they used this resource, and then used this characterization to describe how teachers used the TG to support their planning and instructional decisions related to the enactment of the unit.

As part of the data analysis, teachers were asked to read and respond to their written case. By having the participating teachers read their cases, the author was able to accurately and appropriately capture images of their teaching practice by including their suggested revisions. Then, using the individual teacher cases, the author examined general TG use across both teachers, describing similarities and differences between them. As these similarities and differences were identified, the author then used the interview and observation analyses to describe how teachers used the TG and how they used this resource to manage teaching problems, and develop potential explanations as to why they used this resource in a particular fashion.

In addition, because this study focuses on teachers' use of the CMP TG during planning and instruction, the author systematically analyzed the TG itself. When analyzing the TG, the author focused on the ways in which the TG potentially supported teachers in managing various problems associated with using CMP. When analyzing the teacher cases, the author simultaneously examined the sections of the TG that could potentially influence teachers' planning and instructional practices in these cases.

Research Results

This section presents a brief analysis of the CMP TG and case studies of two 6th grade mathematics teachers. A discussion of the results of the TG analysis is presented first to provide the background needed to understand these teachers' use of the TG during their planning and instruction over the course of the study.

The CMP TG

CMP is an innovative mathematics curriculum that involves a variety of materials, including assessment resources, student books, and the TG. As noted above, the TG is specifically designed to support teachers' practice in a way that helps them meet the potentially significant demands of using an innovative curriculum (Interview with G. Lappan, E. Phillips, 12/6/04). Comprised of two major features, the TG pages corresponding to each lesson include both a detailed Launch-Explore-Summarize (LES) section and a brief At-A-Glance (AAG) section. In general, the LES sections provide extensive teaching notes for enacting lessons, including suggested questions to ask students, examples of student explanations and solution strategies, as well as suggestions for teachers to press students to explain their thinking, and suggestions for soliciting and generalizing from students' proposed strategies.

The AAG section, however, does not consistently support teachers to the same extent. Providing more of a general outline for enacting tasks, the AAG sections do not include the answers to the suggested questions, and often do not include examples of students' explanations or solution strategies as provided in the corresponding LES sections. The AAG section is designed as a resource page that teachers can carry with them when actually working with students and for use in conjunction with the more detailed LES section (Interview with G. Lappan, E. Phillips, 12/6/04). It is important to note that while the two general features of the TG are consistent from lesson to lesson, the substantive content and nature of these features varies, in some cases to a great extent.

Alicia: Selective and Adaptive TG Use

Alicia had been teaching for 16 years and had used CMP for three years prior to this study. Alicia had quite extensive teaching and curricular experience in using more conventional mathematics curricula, as she had used such curricula for the 13 years she taught prior to using CMP. Although she did not participate in the training workshops offered by the CMP developers directly, Alicia had participated in a number of different professional development activities offered by the district, which she indicated in no way impacted her daily classroom teaching. "They did help me get more com-

fortable with the program, but I really don't know that they helped me teach it any better." She continued by stating, "But you know I kind of take and leave what I—take what I need from the meetings. I don't always use everything that we talked about." As discussed below, this "take it or leave it" attitude was also evident in how she used the TG to inform her planning and instructional decisions throughout the unit.

Alicia exhibited strong views about mathematics teaching and learning. She believed that students should spend much of their time practicing certain skills and procedures as opposed to working together and discussing open-ended tasks. Alicia's view of CMP reflected these conceptions of teaching and learning, as she stated that CMP does not provide students with sufficient opportunities to practice skills and procedures, which she felt was "critical to student learning." "…I don't like that they don't give you multiple practice problems of the same type…I wish we had more practice problems with different numbers and they could practice like five more times….That's the big problem with Connected Math." She accordingly viewed her role as a teacher as that of an intervener, providing direct guidance and explicit instructions for students, which was evident in her planning and instructional decisions, as well as her lesson modifications.

Alicia described her use of the TG as consistent from one lesson to the next. In planning for lessons, she said she typically reads through and solves the task in the lesson, making any notes about the solution strategies and any confusing aspects of the task in her personal notebook. After solving the task, Alicia said she then looks through the accompanying TG pages, particularly the AAG section, and decides the most appropriate course of action, taking into consideration both who her students are as learners and the constraints of class time.

> And I kind of pick and choose what I think will work best with my students… Sometimes I'll just interject my own teaching style and how I think the lesson flows better…sometimes it's a matter of time too. And so some things I may choose to leave out.

Alicia's stated tendency to use the TG in a selective and adaptive manner was also evident in how she claimed to use specific features within the TG. The nature of particular questions and aspects of the task, for example, influenced whether Alicia used these features of the TG when planning for and enacting her lessons. "Sometimes I feel like we can cover all the information without doing every single question. And sometimes I just feel like some of the questions just aren't that important to be spending time on." In fact, throughout her enactment of the unit, Alicia rarely incorporated the suggested questions into her lessons, and instead would regularly ask questions that required only single-word or numerical answers.

The following classroom discussion, taken from a lesson involving word problems with decimal addition and subtraction, is illustrative of the nature of the classroom discourse that dominated her enactment of the unit.[4]

> **Alicia:** Can you tell me what type of operation we're going to do? What type of operation?
> **Student 1:** Subtraction.
> **Alicia:** This is a subtraction problem. Tell me, what is the word or phrase that tells me this is going to be a subtraction problem? What is the word or phrase for #1 that tells us we're going to be subtracting here to get the answer?
> **Student 2:** Wait what was the question?
> **Alicia:** I asked, what is the word or phrase that tells you what type of operation we're going to use in #1?
> **Student 2:** How much does she have left to clean?
> **Alicia:** Yeah, but what's the clue word, or one or two words?
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> •••
>
> **Alicia:** Everybody write in their journals this problem right here. What do you notice about the way I wrote this problem up here? What do you notice?
> **Student 3:** I noticed that you didn't match them up.
> **Alicia:** Well did I line up my decimals?
> **Students:** Yes.
> **Alicia:** And that's what we're supposed to do. So what didn't I match up? You're on the right track, but what doesn't match up?
>
> •••
>
> **Alicia:** You are right. I have to add a what?
> **Student 4:** A number.
> **Alicia:** What number am I going to add? I thought you said it a minute ago. What number?
> **Student 5:** A zero?
> **Alicia:** I can add a zero here because guess what, one and five tenths is the same as, is equal to one

> and fifty hundredths. This is just like I divided something into ten equal parts and I took five of them here. Here I divided it into one hundred equal parts and I took fifty....So I can add a zero to the right of my number and it will stay the same number, it will have the same value. Who can walk me through the subtraction real quick?

Following this discussion, students used the remaining class time to begin their homework assignment, which was a non-CMP worksheet that included several naked decimal addition and subtraction practice problems.

As many of her questions throughout the unit were designed to get students to supply the right answer rather than encouraging them to reason through a solution, she tended to portray mathematics as a set of rules and procedures, focusing primarily on using algorithms, and constantly pursuing the right answer during whole class discussions. She also regularly used tasks as individual work assignments as opposed to opportunities for collaborative learning, and engaged in more teacher-directed modes of instruction, despite claiming to have read the TG during planning and to have "highlight[ed] the big ideas." Moreover, Alicia consistently supplemented students' work with practice worksheets from a conventional curriculum to help students learn certain procedures. Though she claimed to regularly use the TG when planning for lessons in the unit, Alicia said she generally uses it to inform the content features of tasks and not to determine which questions she will ask students or how she will organize the whole class discussion. So, while Alicia claimed to use the TG for planning and instruction, Alicia appeared to consider the TG as a resource she can "pick and choose from," and engaged in instructional practices that reflected a more conventional mode of mathematics teaching and learning.

Susan: Prescriptive TG Use

Susan had been teaching for six years and had used CMP for three years prior to this study. Before using CMP, Susan used a more conventional curriculum for three years. Like Alicia, Susan participated in a variety of professional development activities offered by the school district, wherein she learned about the different features of the CMP program and discussed related instructional issues with other teachers. She claimed, however, that these meetings were not useful for her actual teaching of the curriculum, nor did these meetings influence how she thought about the curriculum in general.

Susan's views of mathematics teaching and learning appeared to largely comport with the ideas underlying CMP. For example, she found it helpful for her in maintaining a supportive learning environment for students that the knowledge and the ideas came from the students themselves and not from her telling them how to solve different problems. "And I think it's very powerful for them to see that math isn't some like abstract thing that comes down and is told to them how to do it." Unlike Alicia, however, Susan seemed to regard the TG as an invaluable resource that should dictate what and how content should be taught. Susan said she reads through the TG to ensure she does not extend the discussion of a concept further than what is expected or stated in the materials, and also to gain an overall sense of the lesson and the mathematical ideas embedded in the lesson. "And so sometimes if you're not paying attention, you'll push them farther than they're supposed to go in class. It's helpful to read this [TG]."

Susan accordingly stated that she regularly relied on the TG when planning for and enacting lessons. When planning for a lesson, she first reads through and solves the task in order to think about how students will later approach and solve it, as well as to consider potential solution strategies that may arise. "Because like I said I try to sit down and do the problem myself to make sure like that I know what I'm talking about when I do it with them. And so you know, try to do it different ways." Like Alicia, Susan solved the task herself before reading the TG in order to gain an overall sense of what the lesson entails.

After working through the task, Susan said she reads through the LES section in the TG to understand the overall direction and purpose of the lesson, as well as the CMP authors' intention. "So it's good to read that [TG] sometimes just to see ok, this is only where they need to get to at the end." Susan indicated that she used the TG to not only gain an overall sense of the lesson, but also to understand the CMP authors' rationale for the lesson.

> ...[I]t just sort of you know cued me into some of the things that they were after in the lesson...If I just sit there and the lesson and a student book and not necessarily the teacher's guide, sometimes you're not sure what they're getting after...So if you read through the book, it's like ok, this is you know it really doesn't matter, and now you can let them be very open-ended....So that's helpful to me

a lot.

Susan reiterated this opinion several times, stating that by reading the TG during planning, she was able to understand what the authors intended and to shape her instruction accordingly.

In addition to reading the detailed teaching notes, she read both the suggested questions and answers to the task, and then included these elements in a PowerPoint presentation she used during instruction.

> I usually read through what's in the teacher guide. So like, you know they have suggested questions or it's just sometimes they explain some little blocks you might hit. So I go through and try and you know put some questions up on the [PowerPoint] for notes to put, you know to kind of get the discussion started.

She regularly used the suggested questions, but only included them in her lesson if she decided they are worthwhile and appropriate for her students. "So then I usually read through here and whenever there are suggested questions, I see ok, is this a meaningful question for my students and then if it is, I put it up on the PowerPoint." Susan also said she reads through the LES feature to particularly ensure that she does not extend the discussion of a concept further than what is expected or stated in the materials.

Susan accordingly treated the TG as a prescription for her planning and instructional decisions by following the suggestions and activities precisely as stated in the TG. Throughout her enactment of the unit, she consistently used the TG suggestions to create opportunities for students to work on the lessons, and in most cases, enacted the lessons as described in the TG. Students would work collaboratively on the lesson, and then discuss their solution strategies as a whole class, as described in the TG. Even where Susan debated whether to emphasize a concept that was not included in the TG, she still largely followed the suggestions included in the TG. For example, Susan said it would have been beneficial for students' understanding of decimal addition and subtraction to have some explanation of zero as a placeholder.

> …[L]ike nowhere ever in this whole Investigation do they mention that when you're subtracting and you're missing the place, you need to fill in the zero. That's never covered….So sometimes I feel like these are some really straight things that are kind of glossed over or just assumed to be figured out because they worked so hard on the discovery of the algorithm, which is important but…

Although Susan seemed to believe this issue of the zero placeholder was important for students' understanding, she did not discuss it during her enactment of the lesson, as it was not emphasized in the curriculum. This same issue arose at various points during her enactment of the unit, and Susan resolved this issue in a similar fashion. The following classroom discussion was taken from the same lesson as discussed previously with Alicia, and well illustrates Susan's close adherence to the TG.[5]

> **Susan:** I appreciate that you have this shortcut of saying to line up the decimals, but we really don't line up the decimals. We're lining up what?
> **Students:** The numbers.
> **Susan:** The place values, the numbers in the place values. It just so happens conveniently that our decimal point gets lined up as well. I don't understand why this is wrong [referring to error]…How can I add the 8 in the pretzels to the 1 in the cider? (This was a suggested question listed in the LES section) Why can't I do that? I don't quite understand.
> **Student 1:** You can't do that because they're different values. The 1 is in the dollars value and the 8 is in the cents value. And it's like 8 is 10 cents plus a dollar would be like 100 more dollars or…
> **Susan:** Does anyone have anything to add to that? Does that all make sense to us?
> **Students:** No.
> **Susan:** I like how he explained that. The 1 is in this case is in dollars. And the 8 in this case means 8 dimes. (This explanation of the error was included in the LES section) You added 1 dollar plus 8 dimes to get 9 dollars?
> **Students:** No.

She then described the particular context of and directions for working on the task. She posed the following on the PowerPoint: "As you work, figure out if you need to add or subtract in parts A1-A4. Write the problem and answer in your chart. In your notes, draw a chart like this: [a two-column chart is pictured]." These suggestions were included in the LES section. Susan said to write the problems either vertically or horizon-

tally in the chart. This suggestion was also included in the LES section. Students worked individually until the end of class, while she circulated around the room responding to students' questions. In short, generally agreeing with the underlying ideas of CMP and treating the CMP TG like a script for instruction, Susan engaged in instructional practices that largely reflected the underlying ideas of CMP.

Discussion

In both the case of Alicia and Susan, it appears that there are several important relationships between their teaching and curricular experience, their particular conceptions of mathematics teaching, their conceptions of the CMP TG, and the problems they ultimately faced in using the TG for planning and instruction. In both cases, particular conceptions of the TG appear to have been bound up with teaching experience. Susan, the teacher with less teaching experience, was more reliant on the TG and often treated it as a prescription or script for instruction. The opposite was true for Alicia, who had more teaching experience; her extensive experience with non-conventional curricular resources, which, arguably, differ in the nature of their support for teachers, appear to have made Alicia much less reliant on and willing to closely follow the suggestions of the TG.

In both cases, the teachers' stances toward the TG in turn appear to have influenced the ways in which teachers' conceptions of mathematics teaching and learning shaped their TG use for planning and instructional decisions. Given her stance toward the TG as a resource from which she could adapt and "pick and choose," Alicia's planning and instruction strongly reflected her more conventional conception of mathematics teaching and learning. Indeed, although the TG was designed to support teachers' practice in a way that reflects the underlying ideas of CMP, the TG did little to shape her instructional practice beyond providing the content of different lessons – it appears that Alicia's overall view of what and how students should learn have become somewhat cemented throughout her teaching career and seemed to have hindered her from planning for and enacting the lessons in accordance with the underlying principles, despite the curricular support that was available.

In contrast, Susan's stance toward the TG as a script appears to have resulted in planning and instructional practices that accorded significantly more closely with the ideas underlying CMP. To be sure, Susan's conceptions of mathematics teaching and learning likely influenced her planning and instructional decisions to some extent, as she exhibited a strong orientation to a reform-oriented instructional approach. Susan, however, indicated that she attempted to keep the authors' intent in mind and consistently followed the suggestions in the TG even when she disagreed with them. Thus, it seems that in these two cases, the more teaching experience a teacher has, the stronger and more prominent role their conceptions may play in their planning and enactment of lessons.

Although both Alicia and Susan faced similar sorts of teaching problems on a general level, the precise shape and nature of these problems was different for each teacher. The experiences and conceptions of the teachers appear to explain much of this difference. While both teachers encountered several different types of problems (with varying frequencies) over the course of this study, two types of problems particularly stand out for examining the relationship between experience, conceptions, and teaching problems: (a) treatment of mathematics content in curriculum, and (b) students struggling with instructional tasks.

At various points throughout their implementation of the unit, both teachers anticipated that students would struggle with certain instructional tasks, but the precise nature of this problem and thus the ways in which these teachers managed this problem varied quite dramatically. Alicia, for example, relied on her curricular experience from previous classes to anticipate how students would work on a task involving decimal addition and subtraction. Knowing that students in her previous classes struggled with decimal addition, Alicia planned to enact the task as a whole class activity to help students through the task. Similarly, she anticipated students would struggle with a task that involved computing discounts by again drawing upon her previous experience with the task. As discussed previously, Alicia believed that by implementing tasks as either whole class or individual activities, she was better able to address student difficulties and "guide them in the right direction." Thus, Alicia encountered a teaching problem that arguably many teachers face – students struggling with instructional tasks – but the nature of this particular problem, for Alicia, was that of one that could be managed by her past experiences.

Susan also anticipated that students would struggle with certain instructional tasks, simultaneously drawing upon her previous curricular experience and the suggestions within the TG. Unlike Alicia, Susan, given

her proclivity to use the TG in a prescriptive manner throughout the unit, had to make sense of the information in the TG. Thus, Susan encountered the same teaching problem as Alicia, but the nature of this particular problem, for Susan, was that of one that should largely be managed by the suggestions within the TG and only in part by her experiences.

Another teaching problem that emerged in the case analysis involved the treatment of mathematics content within the curriculum, which further highlights the relationship between experience, conceptions, and teaching problems. In particular, the treatment of long division with decimals from two different instructional tasks emerged as problematic for both teachers. Both Alicia and Susan considered long division as a particularly important concept for students to know and to be able to do. However, the long division algorithm was not explicitly presented in these tasks, but rather presented in the curriculum as a set of interrelated tasks in order to understand the underlying rationale of the algorithm and the role of place value when dividing decimals. Both teachers had to consider how to enact these two tasks in light of their personal stance towards long division. However, only Susan planned to enact the task largely as written, despite her reluctance to do so. Alicia, on the other hand, seemed to rely on her view of what and how students should learn to address her concerns about the mathematics content, and largely planned to focus on the procedural aspects of decimal division in both tasks. Notably, unlike Susan, Alicia used the TG for content purposes in that she used the instructional tasks within the curriculum, with little attention to the suggestions in the TG.

Thus, it appears that both teachers' experience, and their conceptions of mathematics teaching and learning, influenced the ways in which the teachers engaged with the TG, and in turn the precise shape of the teaching problems they encountered. Arguably, the two teaching problems discussed here are problems that most teachers encounter in the course of their work. However, it is also important to note that the teaching problems faced by experienced teachers are compounded further with a particular teaching problem that is unique to experienced teachers' practice, namely the "experience problem." That is, unlike their less experienced counterparts, experienced teachers have to consider how to make active use of their prior knowledge and experience. Thus, in regard to using the TG, the "experience problem" consists of how to utilize experienced teachers' assumptions about and prior knowledge of mathematics curricula. This can be a very difficult task if experienced teachers have a large and diverse body of knowledge from which to draw, especially if teachers have extensive experience with conventional math curricula and are currently using an innovative curriculum. Indeed, in the case of Alicia, the experience problem appears to have significantly influenced the shape and nature of the teaching problems that she encountered and how she managed these problems. Susan, however, largely did not have to concern herself with making use of her prior experiences and encountered teaching problems that focused more on making sense out of the suggestions in the TG.

Given the relationships between teachers' experience, their particular conceptions of mathematics teaching, their conceptions of the CMP TG, and the problems they ultimately faced using the TG for planning and instruction, this study has several implications for future research and curriculum development. First, this study has significant implications for research on teachers' experience. As discussed in the Methodology section, some of this research suggests that teachers become "experienced" after teaching for five years. However, Susan had taught for six years and still displayed some characteristics of what would be considered an "inexperienced" teacher in this research. While Susan could be an anomaly, much of the research on experience is somewhat dated and mathematics curricula have changed significantly in recent years – innovative curricula like CMP embody non-conventional ideas about mathematics teaching and learning, and some curriculum materials, like the CMP TG, are structured to provide support to teachers in the context of the new challenges they face teaching such curricula. This study accordingly suggests that it may be necessary to conduct more research on and reconsider traditional distinctions between experienced and inexperienced teachers, especially where teachers use innovative mathematics curricula.

As few researchers have suggested, the nature and extent of teachers' use of curriculum materials changes over time. For this reason, a longitudinal analysis of Susan's TG use, for example, could examine how her use of this curricular resource changes as she becomes more experienced. In particular, such analyses could highlight whether she relies on the TG to a lesser extent, but still continues to teach in ways that reflect current reform practices. Related studies could conduct longitudinal analyses of inexperienced teachers using innovative mathematics curricula and who display

more conventional tendencies for mathematics teaching and learning. As their curriculum use becomes less prescriptive, does their practice become more conventional or do they become reform-oriented teachers? In other words, does the TG actually work to have a lasting effect on teachers' practice when you get them young? Alternatively, what happens with less experienced teachers who have conventional views of math? While such questions are beyond the scope of this study, it raises several important considerations for research on teacher-curriculum interactions.

The findings and conclusions of this study also have important implications for curriculum development. Can curriculum developers somehow account for the influence of teachers' experiences, given the ways in which teachers, particularly Alicia, engaged with the TG – a curricular resource specifically aimed at supporting her practice in certain ways that did not necessarily work as the developers intended. Arguably, innovative mathematics curricula need to be more persuasive, especially to experienced teachers. Indeed, the TG appeared to support Susan's decision-making throughout her enactment of the unit. As this and other studies make evident (e.g., Remillard & Bryans, 2004), experienced teachers use curricula selectively and adaptively, and make decisions as per their students and the constraints of their classroom. Perhaps curriculum developers can design a curriculum program in such a way that promotes teachers' flexible use of the instructional features within the TG, for example, but that is explicit on large points such as the purpose underlying tasks in order to better position teachers to adapt and use the tasks in line with the overall goals of the curriculum (Ball & Cohen, 1996). Indeed, Davis and Krajcik (2005) propose design heuristics for educative curriculum materials, arguing that the inclusion of the developers' rationale for the task helps teachers understand how the different tasks and activities are connected, making them less likely to treat the tasks as individual and unrelated opportunities for student learning

Conclusion

The problem of experience in mathematics teaching, how one makes sense of and draws from their experiences to inform their instructional decisions, is not new, particularly as reform efforts in mathematics education take root. Arguably, the cases of Alicia and Susan, experienced teachers who found themselves using an innovative mathematics curriculum after having used more conventional curricular for varying years, presented here are not uncommon in mathematics classrooms. In addition to the rapidly growing influence of reform curricula and other documents in mathematics education (e.g., NCTM, 2000), it is increasingly becoming a widespread practice to mandate the use of a single innovative mathematics curriculum in large school districts across the country. In turn, there are a growing number of teachers who find themselves faced with learning to use new curricula, often curricula that embody different modes of teaching and learning than those with which teachers may be familiar. The task for curriculum developers is to design instructional materials (e.g., TG) in ways that make explicit reasons underlying certain tasks and reasons for using certain instructional strategies in particular classroom situations in order to support experienced teachers' effective curriculum use. By providing reasons for the design of lessons, experienced teachers can begin to understand the principled reasons underlying innovative curricula and the classroom environments such curricula can afford. The curriculum design heuristics proposed by Davis and Krajcik (2005) offer one way to address this design issue.

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Author's Notes

[1] The phrase "innovative curricula" refers to curriculum programs that reflect inquiry-based visions of teaching and learning, similar to the ideas underlying several Standards-based mathematics curricula.

[2] Hereafter, "problems" will be used to refer to the challenges and decisions teachers face during mathematics teaching, as described in Lampert (1992, 2001). Lampert's "problems" in teaching are similar to what Ball (1993) identifies as teaching dilemmas.

[3] The assumption is that teachers have developed their own routines in teaching CMP. However, it is possible that external sources, such as professional development experiences and use of other curricula, have affected teachers' routine-making throughout their careers. It is also likely that the repertoires teachers have established around curriculum use reflect the nature of the resources available – more conventional math curricula provide teachers with little guidance and support in planning to enact the tasks and activities with students.

[4] The task discussed in this classroom vignette involved five real-world word problems that required either addition or subtraction of the given decimal numbers. Based on the problem context, students had to decide whether to use addition and subtraction and provide a rationale as to why. In addition, a primary goal of this task was to highlight the need for lining up place values, without explicitly stating as such.

[5] The task discussed in this classroom vignette is the same task discussed previously with Alicia, which involved five real-world word problems that required either addition or subtraction of the given decimal numbers, based on the problem context.

Community-Based Service-Learning as a Source of Personal Self-Efficacy: Preparing Preservice Elementary Teachers to Teach Science for Diversity

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Bandura (1997) contends that when compared to other sources of efficacy, mastery experiences, when presented appropriately, have the most powerful influence on self-efficacy. The purpose of this study was to investigate the effects of community-based service learning (CBSL) experiences on preservice elementary teachers' personal self-efficacy beliefs about equitable science teaching and learning. Data were collected using pretests-posttests and post-questionnaires with the study sample. Findings from this study support Bandura's assertion. CBSL experiences were an important source of personal self-efficacy and significantly influenced preservice elementary teachers' personal self-efficacy beliefs about equitable science teaching and learning.

> When the dismissal bell rings each day, untold thousands of American students depart for home having been taught by science teachers ill-equipped for the job. Far too many are inexperienced beginners, with little to no training…Astonishingly, in no other profession is so much of such ultimate worth entrusted to people with such uneven qualifications (The Glenn Commission, 2000, p. 15).

There is widespread affirmation that many of the nation's schools are failing their students, especially students from nonmainstream backgrounds (Darling-Hammond, 1996). In 1999, Richard Riley, then U.S. Secretary of Education, publicly acknowledged the disparities that existed between the achievement scores of mainstream and nonmainstream students at the Improving America's Schools Conference in Chicago, Illinois. Similarly, the fourth annual 50-state report by *Quality Counts 2000*, meticulously unveiled the poor performance of many students, especially those who attend schools in urban areas.

The demographic divide that exists between today's diverse student population and their future teachers (Hodgkinson, 2002), along with the science achievement gaps between mainstream and nonmainstream students (National Center for Education Statistics, 2005), is of great concern. These gaps are further compounded by the fact that many preservice teachers, the majority of whom possess little to no intercultural knowledge and experiences, continue to enter their student teaching semesters and professional careers unprepared and unconfident in their ability to teach science (Fulp, 2002; Tosun, 2000). Thus, they are ill-equipped to deal with the complexities that may be associated with teaching science to a diverse school-aged population. Although the underachievement of nonmainstream students cannot be attributed to a single factor, one of the greatest determinants of a student's academic success is the teacher. Since teachers' self-efficacy beliefs have been found to be valid predictors of instructional practices (Bandura, 1997; Tschannen-Moran, Hoy, & Hoy, 1998), it is fair to conclude that teachers' self-efficacy beliefs are principle factors that contribute to the academic success or failure of nonmainstream students in science education.

Many teacher preparation programs have failed to positively impact preservice teachers' self-efficacy and beliefs about diversity (Banks, 2001). Evidence from previous studies suggests that community-based service-learning experiences positively influence changes in preservice teachers' self-efficacy (Wade, 1995) and are valuable in creating awareness in white, middle-class preservice teachers of the cultural capital that nonmainstream students bring with them into the classroom (Boyle-Baise, 2002; Wade, 2000). However, such experiences have not yet been integrated into science teacher preparation programs. The purpose of this exploratory study was to investigate the relative importance of various course factors on preservice elementary teachers' personal self-efficacy about teaching science to diverse student groups. More specifically, the following research questions guided this study:

1. What effect, if any, does community-based service-learning, have on preservice elementary teachers' personal self-efficacy about teaching science to diverse student groups?

2. What is the relative importance of various course factors on preservice elementary teachers' personal self-efficacy about teaching science to diverse student groups?

Personal Self-Efficacy

Self-efficacy, as it relates to education, is a teacher's belief or judgment about his or her own abilities to teach effectively. It has been linked to several outcomes such as student achievement, student motivation, and students' attitudes toward school and the subject matter being taught. Self-efficacy has also been associated with teacher behavior. For example, teachers with a stronger sense of self-efficacy are more open to new approaches and strategies for teaching and are more willing to implement innovative instructional practices to meet the needs of their students. They also persist in the face of student failure, are more resilient when facing setbacks, and are more likely to provide special assistance to students who are struggling (Tschannen-Moran, Hoy, & Hoy, 1998; Tschannen-Moran & Hoy, 2001). Ashton (1984) argues, "no other teacher characteristic has demonstrated such a consistent relationship to student achievement" (p. 28). Although self-efficacy has been divided into two cognitive domains, personal self-efficacy and outcome expectancy, this exploratory study specifically focused on personal self-efficacy. Bandura (1997) contends that a person's conception of personal self-efficacy is the most influential construct on his or her everyday life.

Personal self-efficacy is defined as "judgments about how well one can organize and execute courses of action required to deal with prospective situations that contain ambiguous, unpredictable, and often stressful elements" (Bandura, 1977, p. 201). Scaffolding off of Bandura's theory, the importance of personal self-efficacy, as it pertains to science education, was clarified by Enochs and Riggs (1990). They predicted that teachers with high Personal Science Teaching Efficacy (PSTE) would provide increased academic focus in the classroom, exhibit a repertoire of ideas and strategies, and spend more time teaching science.

Ineffective Instructional Practices for Diverse Student Groups

Many teachers subscribe to the belief that very few students, especially non-mainstream students, can be successful in science related fields (Atwater, 2000; Gilbert & Yerrick, 2001; Lee & Lukyx, 2006). This is important because low teacher expectations can undermine teachers' perceptions of personal self-efficacy. Low personal self-efficacy is reflected in teachers' decreased confidence levels, ineffective instructional practices, and consequently low student achievement (Tschannen-Moran et al., 1998).

In their ethnographic study, Gilbert and Yerrick (2001) described the practices of a white male teacher in a lower-track earth science class located in a rural setting, where the majority of students were African American. As opposed to honors science classes, which were comprised mostly of mainstream students, non-mainstream students in lower track science classes were provided with, fewer, if any, lab experiences. In addition, science was disseminated through a watered-down curriculum using fact-based information, absent of meaningful content. Nonmainstream students in lower track science classes were rarely given opportunities to construct arguments and explanations. Similarly, Atwater (2000) delineated a picture in which students of color had been prevented from achieving academic excellence due to obstinate barriers that remain in place. One of those barriers included ineffective instructional practices such as those still exhibited by teachers in charge of educating today's diverse youth.

Science teachers remain the most powerful influence on learning science in urban classrooms (Atwater, 2000). Given the research findings that self-efficacy beliefs are often translated into action (Bandura, 1997; Pajares, 1992), if non-mainstream students are placed in an environment where teachers have low PSTE and expect little to nothing of them, these students are more likely to receive a less rigorous curriculum, be held to low standards, and be placed in special education classes (Harris, Brown, Ford, & Richardson, 2004).

Sources of Efficacy and Community-Based Service-Learning

Bandura (1997) states that there are four sources that influence self-efficacy: *mastery experiences, vicarious experiences, social persuasion,* and *physical and emotional states*. *Mastery experiences* are authentic experiences that are personal and practical. *Vicarious experiences* are those in which an individual observes the performance of another who is perceived to have comparable capabilities. *Social persuasion* involves those instances in which a person is given positive or negative feedback. *Physical and emotional states* are based on responses to stress, fear, and anxiety.

When compared to other sources of efficacy, mastery experiences, if presented appropriately, are considered to have the most powerful impact on self-efficacy (Bandura, 1997). Within the context of teacher educa-

tion programs, mastery experiences are those instances where preservice teachers are provided with opportunities to actually perform the act under question, i.e., teaching. Research findings on the outcomes of mastery experiences in teacher education confirm their promise in enhancing teaching efficacy (Cannon & Scharmann, 1996; Cantrell, Young, & Moore, 2003; Watters & Ginn, 2000). With this in mind, mastery experiences such as community-based service-learning (CBSL) are becoming ever more important.

The diversity of student backgrounds and the increasing number of students from low socioeconomic neighborhoods requires teachers to have an understanding, and appreciation, of students' lived experiences. CBSL engages preservice teachers in activities that address community needs, with structured opportunities embedded within the academic curriculum designed to promote student learning and development. Additionally, CBSL experiences in urban settings can be used as a pedagogical tool to improve preservice teachers' personal self-efficacy, while concurrently preparing them to address the "substantial diversity in experiences students bring with them to school — languages, cultures, home conditions, learning styles, exceptionalities, abilities, and intelligences" (Darling-Hammond, Wide, & Klein, 1999, p. 2). Research studies have documented the positive effects of CBSL on the general construct of teaching efficacy and beliefs about diversity (Root, 1997; Root, Callahan, & Sepanski, 2002; Wade, 1995). For example, Wade found that preservice elementary teachers who participated in service-learning demonstrated gains in self-efficacy and positive attitudes about community participation. Similarly, in a multi-site study of several service-learning courses, Root et al. (2002) found that preservice teachers who participated in service-learning experiences showed increases in self-efficacy. They also found that preservice teachers showed an increased awareness of diversity issues. To the degree that CBSL provides preservice elementary teachers with opportunities to successfully apply effective science teaching techniques, these experiences would be expected to positively affect personal self-efficacy about teaching science to diverse student groups.

Methods

Participants

Participants were 48 preservice teachers who enrolled in two sections of an elementary science methods course at a large urban university in the southeastern United States. The majority of the sample was female (91%), White (78%), and monolingual (85%). Over half of the participants (73%), classified themselves as middle-class, 23% working class, and the remaining 4% upper class. Participants were either in their junior (70%) or senior (30%) year of a 4-year teacher education program.

The instructor was the same for both courses. She was a white, monolingual, middle-class female with science and science education teaching experience in public schools and universities.

The Science Methods Course

Participants self-registered for one of two sections of an elementary science methods course, which met once a week for fifteen weeks in the Spring of 2006. The methods course was a compulsory component of the elementary teacher education program. The general purpose, consistent across sections, was to give participants techniques and materials for teaching science in the elementary school. Preservice teachers also actively participated in, and were guided through, various inquiry-based science activities in large and small groups.

Section One

Course content. This section met at a neighborhood community center every week during the scheduled course time. Each class session consisted of a 1-hour whole group lecture and a 1-hour inquiry-based science lesson that participants were required to implement with the elementary students at the community center. The lecture content covered topics such as science process skills, assessment strategies, students' misconceptions of science topics, inquiry-based learning, and issues related to diversity. In addition, the instructor modeled numerous examples of lessons, along with simple explanations of science concepts, at a similar level to that which was to be used with the elementary students at the community center. Each class session concluded with a 15 – 20 minute debriefing session to discuss the day's activities. Debriefing discussions ranged from science activities gone wrong to how to encourage participation of students who were disengaged from the science activities.

Diversity. Attending to issues related to the interconnectedness of diversity and teaching was an important component of the course. Diversity issues were explicitly addressed via the following activities, assignments and discussions:

- Weekly readings such as Lisa Delpit's (1995) article, *The silenced dialogue: Power and pedagogy in*

educating other people's children and McIntosh's (1993) article, *White privilege.*

- The Draw-A-Scientist Test (DAST): An activity used to examine stereotypical views of scientists (Chambers, 1983).
- Multicultural Awareness Quiz: A quiz that illustrates how an individual's personal perceptions can be in conflict with factual information.
- Autobiographical Narrative Assignment: Students write about how aspects of their identity (e.g., race, ethnicity, culture, class, language) may affect their teaching.
- Discussion Board Questions: Students responded to the following questions:
  - One of the goals for scientific literacy is that all students, regardless of gender, cultural or ethnic background, physical or learning disabilities, aspiration, or interest and motivation in science should have the opportunity to attain higher levels of scientific literacy than they currently do (National Research Council, 1996, p. 6). What is your view of this goal?
  - What does multicultural science education mean to you?
  - Racially/ethnically diverse minorities and women remain underrepresented in science related fields. Why do you think this is?

Community-based service-learning (CBSL). The service-learning component of the course took place in the neighborhood community center. Besides the community center, there are few real diversionary or recreational opportunities available to the neighborhood children. Almost 90% of all school-aged children in this area receive free or subsidized school lunches. The children's families are highly mobile, with attrition rates ranging from 55% to 75% each school year. In addition, the children in this community have poor school attendance, lack parental involvement, and have low academic achievement scores on national and state assessment instruments (University Area Community Development Corporation, 2005).

Approximately 55 elementary students, grades two through five, participated in the CBSL experience. The ethnic/racial composition of the children, based upon the information given by the community center, was as follows: 75% African American/Black, 15% Caucasian/White, and 10% Latino/Hispanic. The majority of students were in the low to moderate socioeconomic status (SES) range.

After the first week of class, participants worked directly with the students, usually on a 3 to 5 basis (3 preservice teachers and 5 elementary school students), for approximately 1-hour a week. This number might have varied from week to week due to student attrition and absences. Throughout the first six weeks of the course, the instructor provided, and modeled, the inquiry-based activities that were to be implemented with the students. For the remainder of the course, participants were required to design and implement their own inquiry-based lessons using the learning cycle model. Briefly, the learning cycle begins with teachers creating interest and garnering curiosity about the selected scientific phenomena. As students explore, the teacher acts as a facilitator giving students opportunities to work together. After the exploration, students are encouraged to share their observations and recordings with peers and the teacher, fostering the development of critical thinking and problem solving skills. The teacher also uses this time to connect student experiences to the phenomena under study. Once the concepts and skills have been labeled, students engage in additional activities in which they are required to apply their recently gained knowledge.

Helping students to develop higher-order cognitive skills was considered to be of the utmost importance by the community center's director. In order to ensure that the participants were taking into account the community's needs, lesson plans were given to the instructor for approval, a week before they were to be implemented. After each course session, participants were required to reflect upon the activities and discussions that took place that day. This analysis described what worked, what did not work, and what major changes participants would make if the lesson were to be taught again. The assessment instrument for the CBSL experience was a portfolio in which each participant included his or her lesson plans, daily reflections, science activities, and analysis of the course.

Section Two

Course content. This section met at the university's main campus. Each week consisted of a 1-hour whole group lecture and a 1-hour inquiry-based science lesson that participants were to implement with their peers. The lecture content covered the same topics as those discussed in Section One. The instructor also modeled numerous examples of lessons, along with simple explanations of science concepts, at a similar level to that which would be utilized with elementary students.

Participant teams (usually 3 preservice teachers) pre-

pared and implemented inquiry-based science mini-lessons, using the learning cycle model (see Section One), with their peers posing as students. However, before implementing their mini-lessons, teams were required to meet with the instructor to confirm that the science content was accurate. Debriefing sessions concluded the day's agenda. During this debriefing time, participants and the instructor provided the team who was presenting the day's mini-lesson with positive feedback and constructive criticism.

Diversity. Like Section One, diversity issues were addressed via the same activities, assignments, and discussions.

Data Collection

Pretests-Posttests

The instrument used for the pretest, administered during the first week of the course, and posttest, administered 15 weeks later, was the Self-Efficacy Beliefs about Equitable Science Teaching and Learning (SEBEST) instrument developed by Ritter, Boone, and Rubba (2001). The SEBEST is a modification of the STEBI-B (Enochs & Riggs, 1990) and consists of 34 items that assess the self-efficacy beliefs of preservice elementary teachers with regards to science teaching for diverse learners. Ritter, Boone, and Rubba (2001) define diverse learners as those groups who are underrepresented in science related fields (racial/ethnic minorities and females) and those from low SES backgrounds.

The SEBEST measures two subscales: PSTE and Science Teaching Outcome Expectancy (STOE). The PSTE consists of 17 items that question preservice teachers about their perceived ability to affect student outcomes based on sociocultural factors such as students' race/ethnicity, SES, gender, and language. The STOE consists of 17 items that assess preservice teachers' beliefs that provided with effective teaching, student outcomes can be positively affected, irrespective of sociocultural background. Each item was linked to a 5 point Likert-scale response ranging from "strongly agree" (5) to "strongly disagree" (1). Possible scores, on each subscale, ranged from 17 to 85.

Ritter et al. (2001) conducted many studies to examine the reliability and construct validity of the SEBEST. In the first study, the SEBEST was administered to 217 preservice elementary teachers. The Coefficient Alpha reliability for the entire instrument was 0.87. Based on this sample, the reliability for the 17-item PSTE subscale was 0.83, and 0.78 for the 17-item STOE subscale. See Ritter et al. for additional tests of reliability and validity. The reliability for this research study was found to be 0.90 for the PSTE subscale and 0.91 for the STOE subscale.

A pre-posttest comparison was used to measure the effect of CBSL on preservice elementary teachers' self-efficacy. Due to the limited sample size, data analyses are based on nonparametric tests. Wilcoxon Sign Ranked Tests were used to detect the effect of each methods course section as reflected in the difference between pre- and posttest scores; and a Mann-Whitney test was employed to measure between-group differences. Since this exploratory study only focused on PSTE, only the results of the PSTE subscale will be presented.

Post-Questionnaires

Post-questionnaires were administered and completed anonymously by participants during the last course meeting. The purpose of the post-questionnaire was to provide data about the sources of PSTE and the relative importance of each source. Closed-ended questions, using a 5 point Likert-scale response of 1 (negative effect) to 5 (positive effect), were used to assess the relative importance of eight course factors on participants' PSTE in regard to teaching science to diverse student groups. The course factors were separated into Bandura's sources of efficacy. Means and standard deviations were then calculated.

Open-ended questions were used to gain further insight into specific course factors that contributed to changes in participants' personal self-efficacy beliefs about teaching science to diverse student groups. Responses were coded and categorized into Bandura's sources of efficacy. The proportion of responses in each category was then calculated for each course section. To check the reliability of the categories, thirty percent of participants' responses taken from each course sections were independently coded by the author and evaluator. Agreement was found in 90% of the responses. When there was disagreement with respect to a particular label assigned to the data, the process was repeated until consensus was reached. The author continued to code the remaining transcripts based upon the established codes and rules for inclusion.

Results

Pretests-Posttests

Before considering between-group differences, it was desirable to determine if enrollment in an elementary science methods course positively affected PSTE.

Table 1
Wilcoxon Signed-Rank Test for PSTE Scores

	Pretest		Posttest		Wilcoxon Signed Ranks Test (Z)	
Section	M	SD	M	SD		p
1	72.05	7.94	79.05	7.27	-3.59	0.00*
2	68.38	6.16	75.19	6.53	-3.70	0.00*

*p values that are significant or approaching significance ($\alpha = 0.05$)

For each section, a nonparametric sign test was employed. The results are shown in Table 1. The sign test showed that the results for both sections were significant, with 20 of 22 participants in Section One ($p < 0.01$) and 21 of 26 participants in Section Two ($p < 0.01$) showing increases in PSTE.

The Kolmogorov-Smirnov Test (KS-test) was conducted on pretest SEBEST scores to assess whether the two methods sections were equivalent. The KS-test did not reveal between-group differences for PSTE scores ($Z = 0.99, p > 0.05$), which indicates that both sections were equivalent at the outset of the study thus permitting further statistical analysis. To determine if the methods section with the CBSL component (Section One) was more effective than the methods section without CBSL (Section Two), the Mann-Whitney test of variation in ranks was conducted using posttest SEBEST scores of PSTE. Data analysis for a difference between the two sections indicated that Section One was more effective than Section Two in enhancing PSTE ($Z = -2.48, p < 0.05$). Additionally, although the course sections were fairly homogenous, demographic variables were applied as grouping variables in order to test for any possible associations with PSTE. No significant associations were found for gender, ethnicity, SES, language, or undergraduate level.

Post-Questionnaires

Forty-eight participants responded to the questions in the post-questionnaire. The questionnaire responses supported the results of the SEBEST. Many participants stated that their PSTE had increased. The quoted selections are chosen as evidence and are not exhaustive of all responses:

> I'm confident because I feel that I was very effective when teaching the students at the community center and I feel that I will bring that into my classroom. (Section 1)

> I think that this experience makes me more aware of other cultures when teaching science. I now feel more confident that I can empower all students to learn science. (Section 2)

Using Bandura's (1997) model for sources of efficacy as a guide, course factors were placed under the appropriate category. These are shown in Tables 2 and 3. An additional category of "Other" was added for those factors that did not neatly fit into Bandura's model.

When compared to other course factors, participants in Section One evaluated mastery experiences (i.e., CBSL) as having the most positive influence ($M = 4.63$, $SD = 1.47$) and readings as having the least positive influence ($M = 3.29$, $SD = 0.99$) on their PSTE in regard to teaching science to diverse student groups. Open-ended responses supported the value of CBSL. Eighty-four percent of Section One's responses attributed gains in PSTE to their CBSL experience. The following are some examples of the comments made by participants:

> Having the experience of the community center has definitely opened my eyes to diverse communities. Working with the kids was a big positive. (Section 1, Mastery Experiences)

> The chance to work with students from different racial/ethnic backgrounds than my own has given me a chance to learn about each child's background, culture, and to see that there are differences to adapt to. (Section 1, Mastery Experiences)

> I think as a future educator my awareness has been heightened by this experience. This is very important because once you become aware you will be able to proactively change expectations. (Section 1, Mastery Experiences)

Participants in Section Two rated vicarious experi-

Table 2.
Science Methods Course Experience Means

Factors by Course Section	1		2	
N	22		26	
	M	SD	M	SD
Social Persuasion				
Collaborative group work	4.30	0.86	4.42	0.86
Instructor feedback	4.08	0.81	4.62	0.64
Vicarious				
Instructor/peer modeling	3.67	1.47	4.54	0.90
Mastery				
Service-learning	4.63	0.39	*	*
Other				
Assignments	3.83	0.80	4.54	0.51
Readings	3.29	0.99	4.23	0.71
Textbook	*	*	*	*
Instructor	3.92	1.16	4.58	0.64

* Not used in this course

Table 3.
Frequency of Sources of Personal Self-Efficacy (percent)

	Section 1 (n = 22)	Section 2 (n = 26)
Mastery	21 (84%)	0 (0%)
Vicarious	0 (0%)	5 (24%)
Social Persuasion	0 (0%)	1 (5%)
Physi/emot States	2 (8%)	0 (0%)
Other	2 (8%)	15 (71%)

ences (M = 4.54, SD = 0.90) and social persuasion ((M = 4.52, SD = 0.75) as having the most positive influence and readings as having the least positive influence (M = 4.23, SD = 0.71) on their PSTE. Although 24% of Section Two's open-ended responses supported the importance of social persuasion, the majority of participants' statements were categorized as "Other." Specifically, most of the statements categorized as "Other" referenced diversity activities, assignments, and discussions (87%). Comments included:

> The feedback given by Instructor Roberts and my peers was invaluable. (Section 2, Social Persuasion)

> It [watching peers teach] helped me develop new ideas and new activities for teaching. (Section 2, Vicarious Experiences)

> Several of the readings in class coupled with group discussions helped. The autobiography helped me to look at myself as well. (Section 2, Diversity Assignments)

The examples described above are representative of the views many participants expressed in the data. Participants attributed gains in PSTE to various methods course factors. However, when mastery experiences were present, these experiences provided the most powerful source of PSTE (Bandura, 1997).

Discussion

Changes in Personal Efficacy about Teaching Science to Diverse Student Groups

This study explored the effects of community-based service-learning (CBSL) on preservice elementary teachers' personal self-efficacy about teaching science to diverse student groups (PSTE). Based on between-group differences for posttest scores on the SEBEST, preservice teachers who participated in CBSL (Section One) experienced greater gains in PSTE compared to those preservice teachers who did not participate in CBSL (Section Two). These positive gains were supported by post-questionnaire analyses. Many preservice teachers in Section One reported strong positive changes in confidence levels as a result of their CBSL experience. These results confirm previous research findings (Root, 1997; Root et al., 2002; Wade, 1995) explicating the positive influence of CBSL on preservice teachers' self-efficacy. Taken together, the results of this study and others appear to provide some evidence to support the effectiveness of CBSL as an alternative strategy for positively influencing preservice teachers' PSTE.

Although preservice teachers in Section One experienced greater gains in PSTE, Section Two's preservice teachers also made significant gains based on pre- and posttest comparisons. The post-questionnaire data support these positive gains and provide evidence to suggest that various course factors promoted gains in PSTE (discussed below). If these results were to have practical significance rather than statistical meaning, it might appear that a science methods course that explicitly emphasizes the interconnectedness of diversity and science is a strategy that is worthy of consideration by the science education community.

Sources of Efficacy

The two sections of the methods course were taught by the same instructor but were situated in different environments. Therefore, all of Bandura's (1997) sources of efficacy, which contribute to perceptions of PSTE, were not present in each course section and experienced by each participant. Bandura posits that there are four sources from which individuals either gain or lose confidence. These sources included *mastery experiences, vicarious experiences, social persuasion,* and *physical/emotional states.* Mastery experiences were gained through direct teaching opportunities at the community center (i.e., CBSL). Social persuasion included instructor feedback and collaborative group work. Vicarious experiences were created when the instructor, or preservice teachers, modeled science lessons and grade appropriate explanations. Physical/Emotional states were preservice teachers' responses to their own fears and apprehensions.

The perception that teaching has been successful raises efficacy expectations that future teaching experiences will also be successful. The perception that teaching has been a failure lowers efficacy expectations, thus contributing to the anticipation that future teaching endeavors will also be unsuccessful. For preservice teachers in Section One, mastery experiences of science teaching were the most important source of efficacy information. It would seem that when preservice teachers were provided with the opportunity to directly engage in authentic teaching experiences with diverse elementary student groups and observe these students successfully carrying out inquiry-based science lessons, their confidence levels were positively influenced. Similarly, after carrying out a study aimed at measuring the impact of site-based experiences of preservice elementary teachers' confidence levels, Wingfield, Freeman, and Ramsey (2000) found that mastery experiences were an important source of efficacy. Their study showed that preservice teachers' confidence in their ability to teach science increased after their site-based teaching experiences. The findings of the present study are consistent with the assertion that mastery experiences, if presented appropriately, have a more powerful impact on self-efficacy than social persuasion, vicarious experiences, and physical/emotional states (Bandura, 1997; Tschannen-Moran et al., 1998). Based on the preservice teachers' comments, implementing science lessons, behavior management, knowledge of students, and working with smaller groups of students positively influenced their perceptions of PSTE.

Social persuasion emerged as an important source of efficacy information for preservice teachers in both sections. The fact that preservice teachers in Section One received verbal feedback from the instructor and students at the community center in the form of engagement, enthusiasm, and active participation, contributed to increases in PSTE. Additionally, responses from both sections suggest that collaborative group work, e.g., grouping preservice teachers to work on a common project, strengthened preservice teachers' beliefs that they were capable of teaching science effectively to diverse student groups. Collaborative group work has been noted to increase teacher efficacy (Scharmann & Hampton, 1995). Group partners seemed to have bolstered the confidence of one an-

other. This finding is in agreement with Desouza and Czerniak (2003) who found that social persuasion helped to foster more positive attitudes in teachers. Furthermore, for preservice teachers in Section Two, the encouragement and advice received from peers and the instructor might have provided a safe environment for preservice teachers to try out new explanations and innovative teaching practices, thus also contributing to gains in PSTE.

Vicarious experiences and "Other" factors were also important sources of efficacy information for preservice teachers in Section Two. Through vicarious experiences, preservice teachers were able to observe the instructor and their peers modeling effective science teaching practices. Some of these practices included facilitating whole and small group discussions, science activities, and teacher demonstrations. The fact that many individuals, whom preservice teachers perceived of the same ability as themselves, were successful in implementing their lessons contributed to the development of preservice teachers' positive efficacy expectations for their own performance (Enochs, Scharmann, & Riggs, 1995). While it is to be hoped that the experiences that occurred vicariously for preservice teachers in Section Two would in fact lead to effective teaching in elementary classrooms, there is a potential problem with this source of efficacy. Preservice teachers are at vastly different educational levels to elementary students. Therefore, it should not be assumed that the teaching techniques that promoted motivation and learning in their peers would be just as effective with young students. Hence, there is a question as to whether these types of experiences could create false efficacy expectations.

The explicit discussions, activities, and assignments that focused on diversity were also an important source of efficacy expectations for preservice teachers in Section Two. They provided valuable insight into preservice teachers' preconceived beliefs about diverse student groups. As these presuppositions surfaced, preservice teachers were compelled to acknowledge how these views might lead to the marginalization of diverse student groups. Preservice teachers explicated that these discussions, activities, and assignments facilitated positive changes in PSTE. A small number of preservice teachers, across course sections, referenced the positive influence of physical and emotional states on their PSTE. One possible explanation for the small number of responses classified as physical and emotional states might be that these states are considered to be the weakest source of efficacy (Bandura, 1997).

Conclusion and Implications

It is a given that all teachers, whether teaching in an urban or suburban setting, will encounter more and more students from diverse sociocultural backgrounds. Ensuring that preservice teachers have the confidence necessary to effectively teach diverse student groups is a major responsibility of teacher education programs. Preparing preservice teachers for the diversity they will encounter in science classrooms necessitates a closer look at strategies for improving self-efficacy beliefs. The results of this study suggest that structured CBSL experiences which are thoughtfully integrated into science methods courses can lead to significant and desired changes in preservice elementary teachers' PSTE and are an important source of efficacy as it relates to teaching science for diversity.

One of the hallmarks of effective teachers of diverse student groups is high self-efficacy (Irvine, 2003). Although high efficacy does not necessarily result in effective teaching, it is a necessary first step. Throughout the semester, preservice teachers experimented with a variety of effective teaching strategies that were acquired in their methods courses and found ways to teach diverse elementary student groups science content and new skills successfully. Because preservice teachers in Section One were provided with an authentic environment within their educational community to foster connections between theory and practice, they showed significant gains in PSTE (Wade & Yarbrough, 1996). The majority of preservice teachers acknowledged that they had developed greater confidence levels in their ability to teach students from diverse backgrounds because of their CBSL experience. These findings have important implications and recommendations for the science education community.

First, if educational outcomes such as persistence in the face of failure, teacher effectiveness, and increased student achievement are all related to self-efficacy, providing experiences that positively effect the development of self-efficacy must become an integral part of teacher education programs. CBSL experiences in culturally diverse schools have been cited as having great potential to positively influence preservice teachers' self efficacy (Boyle-Baise, 2002; Wade, 1995). They also allow preservice teachers an opportunity to become familiar with, and change their thinking about, diverse student groups before they enter their student teaching semesters. Therefore, it is recommended that

CBSL experiences be provided earlier in teacher education programs. Second, the elementary science methods course is usually the first place where strategies for effective science teaching are learned, observed, and modeled. Thus, this course holds the most promise in affecting the needed changes in science teaching efficacy that are required to successfully teach diverse student populations. Teacher educators should provide multiple opportunities for mastery experiences in teaching science to small groups of K – 6 students from diverse sociocultural backgrounds. It is important that these experiences be positive, meaningful, enjoyable, and include frequent opportunities for critical reflection.

Possible areas of further research would include more studies conducted with preservice elementary teachers using the Self-Efficacy Beliefs about Equitable Science Teaching (SEBEST) instrument to further substantiate its reliability and validity. Second, longitudinal studies should be carried out to investigate the durability of changes on preservice elementary teachers' personal self-efficacy as they enter student teaching and their professional careers. The changes in PSTE of preservice teachers in this study might not necessarily indicate permanent changes in self-efficacy. It is only by observing teachers in actual practice that changes in self-efficacy can be confirmed. Research on the effects of CBSL on preservice teachers' self-efficacy is only beginning. Continued research in this area will play an important role in the structure of future preparatory courses for preservice elementary students.

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Connecting Science and Mathematics: Using Inquiry Investigations to Learn About Data Collection, Analysis, and Display

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The purpose of this study was to explore the effect of providing preservice teachers the opportunity to collect real data in a science methods inquiry investigation and using the data, design data displays in their mathematics methods course. The research questions focused on how preservice teachers' understandings of data displays, research design, and the specific content addressed improved when they used these displays to attempt to communicate the data they had collected themselves in their inquiry investigations. The 46 preservice teachers were given questionnaires at the beginning and end of the courses, twelve were interviewed both pre and post, all written work pertaining to data displays and the inquiry investigations was collected, methods class sessions were audio and videotaped, and the final data display and science investigation projects were photocopied. The findings show that by creating and scrutinizing their data displays, the preservice teachers were able to recognize the limitations of their inquiry investigation design. Through working with data in the context of inquiry projects of their own design, the preservice teachers realized meaningful connections and commonalities that exist in mathematics and science while strengthening their knowledge and skills in both disciplines.

Current recommendations in science and mathematics education call for more attention to inquiry approaches and working with data, complementary areas for learning. The National Science Education Standards (National Research Council [NRC], 1996) stress that students should develop the "abilities to do scientific inquiry" (p. 145). Specifically, teachers are asked to provide their students with opportunities to develop their own questions and then design and conduct their own investigations. Teachers are being encouraged to involve students in authentic scientific investigations and work with students on the processes of science rather than focusing narrowly on the laws, concepts, and theories of science (American Association for the Advancement of Science [AAAS], 1993). In order to adequately complete an investigation that involves more than designated questions and a predetermined experimental design, students should be challenged to generate their own questions, learn and use appropriate data collection techniques, be able to analyze and interpret the data they collect, and propose descriptions and explanations based on their data.

Similarly in mathematics, the National Council of Teachers of Mathematics (NCTM, 2000) calls for teachers to include more data representation (e.g., tables and graphs) in the lessons they teach. According to Konold and Higgins (2003), students, as well as teachers, need experiences working with real data to develop skills and understandings about graphs and their uses. Working with data, learning how to analyze and represent data, allows students to improve their ability to understand and communicate using graphs and other data representations.

The majority of preservice elementary education undergraduates have had little if any experience conducting an inquiry investigation on their own (Bransford & Donovan, 2005; Smith & Anderson, 1999). Given their limited training in science, preservice elementary teachers have not had opportunities to develop an understanding of how science is done. Very few preservice teachers planning to teach at the elementary or middle grade levels have had science courses where they engaged in collecting, analyzing, and displaying data. Typically, preservice teachers have had at the most one college course that included data collection, analysis, and display and little or no experience learning about data in their own K-12 educations (Konold & Higgins, 2003) and therefore do not have clear understandings of how to collect, analyze, interpret, or display data. With increased expectations that students understand data (Conference Board of the Mathematical Sciences, 2001; NCTM, 2000; NRC, 1996), preservice and practicing teachers are challenged to teach their students without ever having experienced working with data themselves.

Literature Review

Research has indicated that teachers may not adequately be prepared to teach students about collecting, analyzing, and displaying data in ways that support meaningful learning (Bransford & Donovan, 2005; Konold & Higgins, 2003). In part, this lack of pedagogical content knowledge about teaching data collection and representation may stem from weaknesses in content understanding of mathematics and science (Ball, Lubienski, & Mewborn, 2001; Magnusson, Krajcik, & Borko, 1999). Research using Trends in International Mathematics and Science Study (TIMSS) data indicates that teachers are not changing to meet NCTM Standards in regards to including more data representation in their teaching (Jacobs, Hiebert, Givvin, Garnier, & Wearne, 2006). Understanding data analysis and representation involves higher level thinking including: interpreting what numbers on a graph represent, selecting appropriate ways to summarize and compare groups or categories, and identifying relationships and patterns in the data. Students need experiences working with real data in order to develop these skills and understandings in preparation for interpreting data throughout their later life (Friel, O'Connor, & Mamer, 2006; Konold & Higgins, 2003).

Preservice teachers, even after having taken science and mathematics content courses, may not have a clear understanding of how to collect or make sense out of data (Roth, McGinn, & Bowen, 1998) and are unable to perform the practices that scientists do when interpreting data or graphs (Bowen & Roth, 2005). This weakness may be due to never having been involved in authentic investigations in their content courses where they collected data themselves and were responsible for communicating what the data meant (Bransford & Donovan, 2005; Smith & Anderson, 1999).

Various approaches have been found to improve preservice teachers' understanding of science processes. In a case study involving a preservice teacher, Shapiro (1996) found that designing and conducting authentic investigations led to an improvement in the students' understanding of nature of science and inquiry. In a study involving preservice secondary science teachers conducting inquiry with scientists as facilitators, Melear, Goodlaxson, Warne, and Hickok (2000) found that inquiry experiences provided the participants with increased self motivation and increased skills in communication and critical analysis. Haefner and Zembal-Saul (2004) established that preservice teachers involved in science investigations in a life science course developed more appropriate understandings of science and scientific inquiry and were seen to be more accepting of teaching inquiry science in the classroom.

Involving preservice teachers in science investigations where they are asked to work with data has been shown to improve their understandings of data representation. In a study where preservice teachers were asked to carry out guided inquiry investigations, Lunsford, Melear, Roth, Perkins, and Hickok (2007) found preservice teachers improved in their ability to transform data into complex and abstract forms and increased the number and type of representations they made of their data. When involved in authentic science inquiry projects, students can be asked to use graphs and data representations both as tools for analysis and communication tools for illustrating ideas (Friel, Curcio, & Bright, 2001).

Involving preservice teachers in inquiry science investigations where they are asked to incorporate mathematics and technology skills has been successful in improving how these preservice teachers view the connections between mathematics and science (Heflich, Dixon, & Davis, 2001). Kelly (2001) found that by involving preservice teachers in an inquiry project involving mathematics and science provided the teachers with concrete strategies for teaching mathematics and science and improved their confidence to teach these two disciplines. However, meaningfully connecting mathematics and science can be challenging for teachers.

Teachers in science and mathematics have attempted to connect the two areas since the beginning of the twentieth century (Lehman, 1994). In studies on teachers and university mathematics and science professors, researchers found that challenges to connect the disciplines included insufficient instructional time to effectively build connections and lack of content knowledge in both disciplines (Huntley & Watanabe, 1998; Lehman; McBride & Silverman, 1991). Indeed, Lehman found that less than 50% of practicing and preservice teachers believed they had sufficient content background to connect mathematics and science in instruction. In spite of these challenges, educators and researchers remain committed to the value of connections and recommendations that teacher education programs focus on preparing teachers to incorporate mathematics and science connections in their instructional practices (Huntley & Watanabe; Lehman; McBride & Silverman). But in the research reviewed, we were not able to find in depth discussion or recom-

mendations on models involving elementary science and mathematics methods courses or strategies elementary science and mathematics methods instructors might effectively employ to connect science and mathematics; therefore, we have presented our model and the research we conducted on the effectiveness of this model.

Research Questions

The research questions guiding this study focused on how preservice elementary teachers developed in their understanding of data through experiences in inquiry science. Specifically, the questions driving the research were:

- How are preservice teachers' understandings of experimental design, data collection, and analysis affected by the experience of designing and carrying out their own science investigation?
- How are these teachers' understandings of interpreting and displaying data affected by focused instruction and generating data displays of their own data?
- What are preservice teachers' projections about their plans for making connections between mathematics and science in their own future teaching after having experienced this model in their methods courses?

Methodology

Project Overview

In order to improve preservice teachers' understandings about and skills in using data collection, analysis, and display methods, a project was designed that involved preservice elementary teachers conducing a semester-long individual inquiry investigation in their science methods course while learning about data analysis and display in their mathematics methods course (see Appendix A and Roth McDuffie & Morrison, 2008), for a description of activities and assignments in both courses). In the science methods course, after instruction on the nature of science and scientific inquiry as well as experimental design, the preservice teachers selected a topic for their research (options included: the moon, plant growth, invertebrates, or weather conditions). After conducting background research on their chosen topic, the preservice teachers formulated questions, made predictions, collected data, proposed explanations, and summarized their learning. All information was recorded in the preservice teachers' science notebooks (see Morrison, 2008, for more description of this inquiry project). In the mathematics methods course, after data collection was completed, the preservice teachers participated in small and large group activities focused on understanding and creating graphical displays. Each preservice teacher then created at least three different data displays from data collected as part of their inquiry investigation in the science methods course. The assignments in the two methods courses were designed and articulated so that they modeled connections between math and science and the instructors discussed with the preservice teachers the possible learning opportunities in math and science that this type of project presented. Throughout both of the methods courses, the focus was on challenging the preservice teachers to take responsibility for their own learning about inquiry investigations and the resultant communication and explanation of their results.

Participants

The participants in this study were 46 undergraduate preservice teachers working towards certification to teach at the K-8 levels. These 46 were the total number of preservice teachers enrolled in two sections of a science methods course and two sections of a mathematics methods courses during the 15 week semester of the project. Only those preservice teachers enrolled in both science and math methods concurrently were eligible to participate, all eligible preservice teachers agreed to be a part of the study. Prior to enrolling in the education program, these preservice teachers had typically taken two science and two mathematics content courses at the local community college. The names of all participants have been changed to preserve anonymity.

Data Collection

Questionnaires. At the beginning of the semester, the preservice teachers enrolled in the science methods and mathematics methods courses were given two prequestionnaires, one in each of the methods classes. The science prequestionnaire was designed to assess understanding about developing investigable questions, experimental design, independent and dependent variables, and drawing conclusions based on empirical evidence. The prequestionnaire given in the mathematics methods class provided baseline data on participants' comprehension of common graphs (e.g., circle graph, scatter plot, line plot, box and whisker graph, bar graph, line graph, and stem and leaf graph) and creating data displays. Participants were also asked on the mathematics prequestionnaire to analyze 4th grade students' responses to data-related questions; these items were released items from a state mathematics assessment. During the last week of both the methods

courses, post questionnaires containing items parallel to the prequestionnaires were administered; one in science methods and one in math methods. The post questionnaires were similar in length and difficulty to the prequestionnaire. The preservice teachers were informed that their responses on the questionnaires (and interviews) would have no impact or influence on their grades in the courses. Sample questions from the science and mathematics pre and post questionnaires are provided in Appendix B.

Interviews. After completion of the prequestionnaires, the researchers interviewed twelve participants. We selected the twelve interviewees based on their understanding of the material communicated on their prequestionnaire with the intention of forming a sample of four preservice teachers at each of three levels (low, medium, and high). During these interviews, lasting from 30-45 minutes, the preservice teachers were provided with a copy of their questionnaire and asked to reflect and elaborate on each of their responses from both the science and mathematics prequestionnaires. At the end of the courses, the same twelve participants were interviewed about their post questionnaire responses in a similar interview.

Student work. Throughout the semester, work generated by the preservice teachers relating to their inquiry investigations and data display project was collected and photocopied. The student work collected throughout the semester included: reflection papers on the inquiry and data projects; science notebook entries; drafts of formative work interpreting and displaying data; and written comments and feedback from peers and instructors. The preservice teachers were asked to write a reaction paper for each methods course at the end of the semester regarding the inquiry assignment and using science notebooks (for science methods) and the data display project (for mathematics methods). For science methods, they responded to the following prompts: "Discuss your views about the individual inquiry investigation you conducted. What did you learn? How did collecting real data and learning how to display this data help in your understanding of the science concepts involved?" This was not a graded paper, they were given three points for doing the paper and zero points if not completed, and no evaluation of their ideas was involved. For mathematics methods, preservice teachers responded to prompts as described in Appendix A, Week 12. In their science notebook, in a separate writing assignment, the preservice teachers were asked to write about how they might use what they had learned doing the inquiry project in their future classrooms when teaching science. These papers were all photocopied as a data source on the preservice teachers' views on their own learning throughout the connected projects and how they might incorporate the approaches, concepts, and processes from the projects in their future teaching practice.

Field notes. Throughout the semester, the instructors kept field notes documenting various interactions with students relevant to the project and recording pertinent classroom interactions. Comments the preservice teachers made informally regarding their projects were collected in order to gain an impression of the preservice teachers' struggles when collecting or displaying data.

Data Analysis

The questionnaires given in the science methods course were analyzed according to a 3 point scale based on whether the preservice teacher had shown evidence of including integral parts of an investigation when given a scenario and asked to generate a question, design an experiment, and make a prediction. They were given score of 0, 1, 2, or 3 based on evidence of: a) an investigable question, b) the materials and a method to collect meaningful data, and c) the identification of independent, dependent, and controlled variables. The mathematics course questionnaires were analyzed in order to identify the knowledge held by the preservice teachers regarding a variety of different data displays. Each of the items on the mathematics questionnaires were analyzed on a 2 point scale based on evidence for the extent to which the participant reasonably and meaningfully interpreted and/or generated various forms of data displays; a score of 2 represented complete, well developed understanding; a score of 1 for demonstrating some understanding; and a score of 0 when insufficient understanding for teaching was evident. After scoring each item, item specific analysis across all participants was conducted and item scores were compared for each participant. We also computed and analyzed the total scores for participants.

In order to triangulate findings, the twenty four interviews (12 pre and 12 post) were transcribed and analyzed. The statements and responses made by the preservice teachers relating to their questionnaires were compared to what they had written when completing the questionnaire and/or their written work/data displays. We searched for commonalities, differences, and patterns in the interview transcripts, as well as all writ-

Table 1.
Questionnaire Results (n = 46)

Methods Course	Pre Questionnaire Average	SD	Post Questionnaire Average	SD	t-test	Effect size
Science	72.0%	28.71	91.0%	23.29	-6.03	0.66
Mathematics	60.7%	12.65	70.3%	14.20	-4.47	0.76

ten work and instructors' field notes. Specifically, we used the following categories to organize and reduce the data: a) changing understandings about conducting inquiry investigations, b) changing approaches and/or thinking about generating and/or analyzing data displays, c) looking at data in graphical form to help redesign the experiment, d) selecting appropriate data displays, e) planning to use inquiry science when teaching, f) connecting mathematics and science, and g) using similar projects in their own future teaching.

The science notebooks containing the preservice teachers' individual inquiry investigation were collected and photocopied at the end of the course. We analyzed the structure of the inquiry investigation. Specific questions that followed from our first research question relating to inquiry included: Was there a meaningful, researchable inquiry question?; Was there evidence of research on the topic completed in order to refine and focus the question?; Were valid, relevant data collected over a period of a minimum of six weeks?; Did the data display and summary demonstrate understanding and relate to the question?; and Was an explanation for the findings proposed based on the data collected? After an initial reading of the assignments, a ranking of "+" was given to any assignment with evidence of all the above and a more in-depth analysis of the investigation was left until later. If any of the elements were missing, the assignment was categorized with a "0". A more comprehensive reading was conducted in order to identify evidence of changes in how the investigation was conducted. For example, did the inquiry question change as the preservice teacher realized it needed to be more specific or researchable? Were more or different data collected as the investigation progressed and the preservice teachers saw that their data needed to be more specific? Was more external research conducted when the preservice teacher found more information was necessary to make a final explanation? The assignments marked with a "0" were also reread and the most common investigation failures were used to categorize the "0" assignments. The categories that were developed from the most frequent problem areas were: a) research question was not investigable, b) not enough or the wrong types of data were collected, and c) the conclusion proposed was not based on the data collected.

Findings

We found that preservice teachers' understandings of experimental design, data collection, and inquiry investigations were affected by the experience of designing and carrying out their own science investigation. These preservice teachers showed a significant improvement in their understanding of experimental design as evidenced by their science questionnaire scores (see Table 1). Scores from the mathematics questionnaire demonstrated the project impacted the preservice teachers' learning about data display and they developed improved understandings for generating and interpreting data representations. We found that the post scores on both the science and mathematics questionnaires were significantly higher (see Table 1).

The effect size for both the science and the mathematics questionnaires was calculated by subtracting the mean score (%) of the prequestionnaires from the mean scores of the post questionnaire and then dividing the difference by the standard deviation of the prequestionnaire. According to Orlich (1996):

> An effect size of 1.0 can be interpreted as a gain of one standard variation on a normal curve for the treatment group. An effect size of 2.0 is phenomenal. At 0.3, an effect size becomes useful or important. Effect sizes of less than 0.2 are usually not important. An effect size of 0.25 begins to show importance. (p. 76)

The effect size for the mathematics questionnaires was seen to be 0.758 and the effect size for the science questionnaire was established at 0.66 indicating medium to large effect on learning in both areas (Orlich, 1996).

From the inquiry investigation assignments, evidence was gained regarding the preservice teachers'

struggle towards understanding how to collect data and carry out an inquiry investigation. For example, many stated in their reflections that the assignment was the only way they could have learned how to do inquiry, by being forced to do it themselves. Conducting the experiment on their own allowed the preservice teachers to gain insight into how difficult it is to set up a valid investigation. One preservice teacher commented:

> By recording my data I also realized that a lot of my data was inaccurate. I don't think I would have realized that if I were just watching the plants grow without having to record anything because I wouldn't have been forced to analyze if it made sense. (Jenna, final reflection)

Another quote was "I learned that next time I need to look for specific things instead of just observing everything randomly." Many of the preservice teachers expressed a new understanding of investigable questions and the following quotations from the preservice teachers demonstrated their growth in understanding of conducting inquiry investigations:

> The individual inquiry investigation was a learning experience I will not forget. Not only did I learn about ants, but I learned how to set up a science inquiry project. I went through the struggles of creating a good test environment and making sure my data would be reliable and consistent. (Marie, final reflection)

> When I began my science inquiry I knew what I was planning on testing for, but I did not know how to gather the data. I changed my data collection table many times throughout the process; at times it was very frustrating. (Jeremy, science notebook final entry)

The preservice teachers were encouraged to orally share any progress or problems they were having during the inquiry investigation. These comments were recorded in field notes by the instructors. A concern that regularly surfaced with the preservice teachers was what to do when no data could be recorded. The most characteristic comments made were:

"Nothing has happened for days, I can't record anything."

"I couldn't see the moon, there was nothing to record."

"There was no moon last night!"

"My plants aren't doing anything."

"There is no change so there's nothing to record." (Field notes)

These comments allowed for a discussion on how no change in a phenomenon may still be an important quality to record and that a recorded quantity of zero or simply stating "no change" may be informative later in the study. The preservice teachers studying the moon were assured that "no visible moon" was still important data.

In order to illustrate the growth made in these preservice teachers' understandings of data analysis and data display and show how focused instruction and analyzing and generating data displays of their own data affected their understanding, we provide below a specific and representative example of one preservice teacher's growth. Nadia's inquiry project and her exploration of an area graph (See her area graph in Appendix C) are described in detail. While exploring options on Microsoft Excel™, Nadia created an area graph to compare plant growth using data from two plants (treated with and without fertilizer). Nadia decided the graph was incorrect when she misinterpreted the non-fertilized plant on Day 15 as measuring 16 cm (taller than the fertilized plant), she did not understand how to read an area graph (e.g., on day 15 the height is found by subtracting 6 cm from 16 cm, or 10 cm). But because she collected her own data, Nadia knew the fertilized plant height was taller; she recognized that either something was wrong with the graph or with her interpretation of it. During the data workshop, Nadia and her group make sense of an area graph display and discussed how graphs can be different from what they seem. Nadia decided not to use this display as her final display because she and her group thought other readers could be confused by the area graph, it was not appropriate for elementary students, and this display could lead to an incorrect interpretation of the data. For her final graph, Nadia generated a double bar graph, showing the heights of two plants each day of the observation period. She explained, "The bar graph is a more clear representation of the difference [of the heights] day-by-day." Although Nadia's comparisons of area and bar graphs demonstrated improved understandings, further work with double line graphs might have strengthened understandings even more. She did not discuss how a double line graph could be better than a double bar graph for the continuous data she col-

lected.

This project supported the preservice teachers in understanding that conventions exist for reading many forms of data displays, and being unaware of these conventions may lead to incorrect interpretations. They gained new insights for the importance of considering the audience reading the display and saw that simple graphs often were more effective at conveying information; they also recognized that some forms of data displays are more appropriate than others for elementary students' learning.

Regarding the third research question, What are preservice teachers' projections about how they would make connections between mathematics and science in their own future teaching after having experienced this model in their methods courses?, we found that these preservice teachers wrote about how they might use inquiry science investigations when they have their own classrooms. The majority of the responses contained some reference to how they could motivate students by using inquiry science investigations and enrich learning by including mathematics concepts in the investigation. Representative quotes were:

> This process [inquiry project] helped me to understand science concepts better than I ever had before. I doubt a text book or videos would have taught me half of what I learned by doing my own investigations. I now understand how important inquiry science is to student learning. I can't wait to use it in the classroom. (Randy, final reflection)

> Doing this study has allowed me to see how much freedom and ownership students are able to have in their own learning when science inquiry is implemented. (Jackie, final reflection)

By experiencing all phases of inquiry, participants gained understandings for the kinds of experiences learners need to understand data representations and approaches to teaching through math and science connections. One preservice teacher reflected on applying this project to her teaching when she wrote,

> Using what I learned from this project, I would assign an inquiry science exploration or some other data [collecting] project to my sixth graders. Based on my own experience, I think the students will struggle most with how to best represent their data… [My] students would input and produce their own sets of data using appropriate technology and present them to the class. I like the idea of students asking for peer feedback prior to completing the assignment because it raises the quality of the final product. (Barb, final reflection)

Another preservice teacher reflected that collecting and graphing her own data was important and explained,

> When I was in elementary [school], we created a bar graph, but my teacher gave us all the needed elements and all we had to do was plot the points or make it into a bar graph…. I never truly created a graph on my own…. I needed to understand how to make a concise graph that shows what I want it to show. (Jessica, final paper)

Another commented on the value of using a graph in her project and how this would also be true for her students,

> The one thing that I really liked about the investigation was how we had to display our data on a graph…If I were to look at my data table, I wouldn't have been able to see the growth the same as I did when I was looking at it on a graph. If the grade I am teaching is old enough to use excel (sic), I will DEFINITELY have them create graphs on the computer, this is one concept that is so important for students to do and see. (Cherie, final paper)

Conclusions and Discussion

We found that these preservice teachers' understandings of data collection, analysis, and display were affected by focused instruction and attempting to generate displays of their own data collected in their inquiry investigation. From the prequestionnaire and pre interview responses, many of the preservice teachers could read common forms of data display and make graphs from given data sets at the beginning of the study but when asked to generate their own displays using real data, they did not have a deep understanding for applying this knowledge. By creating, analyzing, and evaluating three different data displays from their own data set, the preservice teachers critically compared the benefits and limitations of a variety of displays for various purposes and strengthened their understandings of data displays. Although they demonstrated a stronger knowledge of reading and generating

data displays on the post questionnaire, the greatest growth was seen in how these preservice teachers were able to design a data display to use to communicate their own findings. As the preservice teachers explored different ways to display the data they had collected and attempted to convey the results of their investigation to others, they began to see that some types of data displays are better suited than others to convey the intended results.

The preservice teachers in this study moved beyond merely understanding the structural outline of an investigation; prior to conducting their own investigation they used the required vocabulary for investigative design in elementary and middle grades (i.e., terms such as prediction, manipulated, responding, and controlled variable, and conclusion) but they showed little depth of understanding of the terms on the prequestionnaires. After conducting their own inquiry project and being required to identify these terms in their own investigation, the preservice teachers improved in their use of the terms.

Although our findings allow us to conclude that these preservice elementary teachers did improve in their understanding and use of data displays, this growth was tied to their own data and their understandings may have been specific to the study they completed. Moreover, our questionnaire and project findings indicate that many of the preservice teachers need to continue to develop understandings of data and inquiry. As others (Roth et al., 1998) have demonstrated, fostering the ability of preservice teachers to work with data and understand data displays may not be easy. It has been shown that even secondary preservice teachers with degrees in science and students with extensive science training may not easily become experts at data collection, display, and analysis (Roth & Bowen, 1994; Roth et al.). Although this project established a strong foundation for understanding data display, we recognize that more time and experience will be needed before these preservice teachers hold a solid understanding of data analysis and display.

This project sought to document preservice teachers' ideas about making connections between mathematics and science in their own future teaching after having experienced this model in their methods courses. We were interested in finding out how modeling learning opportunities built on connections between mathematics and science might influence preservice teachers' projected plans to implement similar projects when they begin teaching. The statements made indicate that these preservice teachers plan to implement a similar type of activity when they teach math and science (with appropriate adjustments for children's learning needs), and that they recognize that this model is an effective strategy to use to develop understandings for both math and science concepts to students. We plan to research the teaching practices of these teachers when they have their own classrooms in order to determine if they are implementing any part of the model presented to them in these methods courses.

Limitations

In this study, we recognized limitations that may have impacted our conclusions. We were not able to follow the preservice teachers past the methods courses and observe them in their student teaching or full time teaching experiences. Therefore, the projections they made may have been made solely for the assignment they were asked to complete on how they would connect mathematics and science in their future teaching. We could not establish that these preservice teachers would in fact connect mathematics and science in their own teaching.

Implications

The preservice teachers who completed the inquiry investigation in their science methods courses demonstrated that they were able to conduct investigations incorporating investigable questions, experimental or observational data collection, and valid conclusions based on their data. As was seen in previous studies (Haefner & Zembal-Saul, 2004; Shapiro, 1996), when preservice teachers are involved in inquiry, their understanding of inquiry science and the nature of science improves. By working with data in the context of student-developed inquiry projects, preservice teachers realized meaningful connections and commonalities that exist in mathematics and science while strengthening knowledge and skills in both disciplines. In addition, they gained insights for how a project similar to this data and inquiry project might be implemented with elementary students.

When the preservice teachers become classroom teachers, they will be asked to teach students about investigations in science, their inquiry assignment experiences will provide them with a model to use when involving their own students in authentic inquiry experiences. These teachers will also be required by the state standards to teach students about data representation and through their experiences learning about dis-

playing their own data, will be better prepared to do this.

State science tests contain scenarios where students are required to demonstrate skills such as: posing questions about the scenario, making predictions, identifying variables, designing investigations, analyzing data, and making conclusions. Similarly, mathematics tests often require students to graph data and analyze tables and graphs to form conclusions from data. All these skills were involved in the preservice teachers' inquiry assignment and they will therefore be better able to help students master these skills in the classroom.

Based on our experiences in this project, we offer the following recommendations. The mathematics and science connections need to be authentic and purposeful, both for effective time use and to successfully model meaningful connections in instruction. In our case, both disciplines truly served each other during the project, and the learning goals closely overlapped to satisfy needs for both courses. By selecting a project that serves both courses, both professors experience benefits for their students and are more likely to engage fully in the collaborative effort. To overcome limitations in content-area expertise, collaboration with colleagues is essential in designing and implementing the project (including coordinating assignment due dates and class discussions). In communicating, we each shared perspectives from our disciplines that helped to support students learning across both mathematics and science.

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Appendix A

Project Activities and Assignments Timeline

WEEKS	PRESERVICE TEACHERS:
1	**Completed questionnaire to assess understandings** in areas of: forming questions, designing experiments, collecting and analyzing data, comprehending common graphs (see types listed below under Weeks 8 – 9; both courses). **Participated in inquiry based science lessons** and discussed key aspects of teaching and learning with inquiry-based approaches (Science methods).
4/5	**Began designing their inquiry investigation projects.** Individually or in a small group, this involved forming a question, designing an experiment, collecting data (for at least 6 weeks), analyzing their data (including generating data displays), and reporting findings. Topics for study included: weather conditions, invertebrates, plant growth, and moon phases (Science methods).
8/9	**Participated in small group activities focused on understanding and creating graph displays**. Groups presented graphs to the class and the class discussed what each graph showed or did not show about the data, how each graph enhanced or limited data analysis, how graphs are useful both for analyzing/making sense of data and for communicating ideas or persuading an audience (Math methods). Specific topic groups (weather, moon, invertebrates, or plants) met to share resources, ideas, and struggles for 20-30 minutes each class session (Science methods).
11	**Participated in a data analysis workshop**. Prior to this class, each student created at least three different data displays from data collected as part of the inquiry investigation. Group and final discussions addressed: What does each graph reveal or not reveal about the data? Which display is the best choice for the data and research question? Examine other ways of displaying data and decide if another data display might be more appropriate. How does the process of data display help you to make sense of your data? What do you need to consider when communicating findings to others? What are implications for teaching and learning data display to elementary school students? What are the benefits and limitations of connecting mathematics and science in studying data collection, analysis and display? (Math methods).
12	**Submitted a Data Display Report.** The report contained the following: A description of the inquiry question with background for the reader to use in interpreting the data display(s); Drafts of at least three different data displays for the inquiry project; A final data display (revised from one of the above drafts or a new display that was generated after the data workshop); Explanation and analysis of the data displays and why the final display was selected; Reflection on learning, misconceptions, and/or gaps a student held prior to the data analysis project, new insights and/or knowledge, how this project promoted learning about data analysis concepts and processes, and how making connections between the disciplines of mathematics and science enhanced learning; Reflection on future teaching and learning (discussion of anticipated issues children might encounter in learning about data analysis, possible approaches to instruction in light of these issues, connections and background knowledge to use in instruction, and the role of technology in teaching and learning data analysis);(Math methods).
14	**Submitted an Inquiry Investigation Report** containing: An explanation of and background research on the topic; Observations recorded over a six-week period; Data table(s) of observation data; Data display (final display from the math methods course); Conclusions/ explanations about patterns discovered in the investigation; Reflection on learning and future instruction (Science methods).

Appendix B

Examples from Science Questionnaires

Science:
Problems 1-5 (out of 6)
The Grass is Always Greener (adapted from the Washington Assessment of Student Learning, OSPI)

Directions: Use the following information to answer numbers 1 through 5.

Jose and Maria noticed the grass in one part of the yard was growing better than in other areas. They thought this happened because parts of the yard received more light than other parts. They did the following investigation with *grass sod* (a layer of grass with its roots in soil).

Prediction:
Grass that receives more light will grow the tallest.

Materials:
grass sod cut into 3 equal pieces meter stick
water
200 m L beaker
3 trays of the same size
3 lights connected to timers

Procedure:
Set the three pieces of *grass sod* into the three trays and put the trays in a dark place with the lights above them.
Measure the average height of the grass in each tray and record as starting heights.
Set the timers to turn the lights on daily: one light for 2 hours, one light for 6 hours, and one light for 12 hours,
Water each tray with 200 mL of water every four days.
Measure the average height of the grass at the end of each week.
Record the average heights in the data table for 3 weeks.

Data:

Amount of Light Vs. Height of Grass				
Amount of Light (hour)	Average Height of Grass (cm)			
	Start	Week 1	Week 2	Week 3
2	1	2	3	4
6	1	3	5	7
12	1	5	9	13

1. What question were Jose and Maria asking in their investigation?
2. Why is soil important to the plant in Jose and Maria's investigation?
3. Which variable did Jose and Maria change (manipulate) in their investigation? What variable(s) was controlled? What was the responding (measured) variable?
4. Write a conclusion that explains whether Maria and Jose's prediction was correct.
5. Formulate a new question based on the conclusions you made for Jose and Maria's investigation and write a plan for an experiment that would answer the questions you came up with.

Examples from Mathematics Questionnaires

Mathematics:
Problems 1-7 (out of 10):

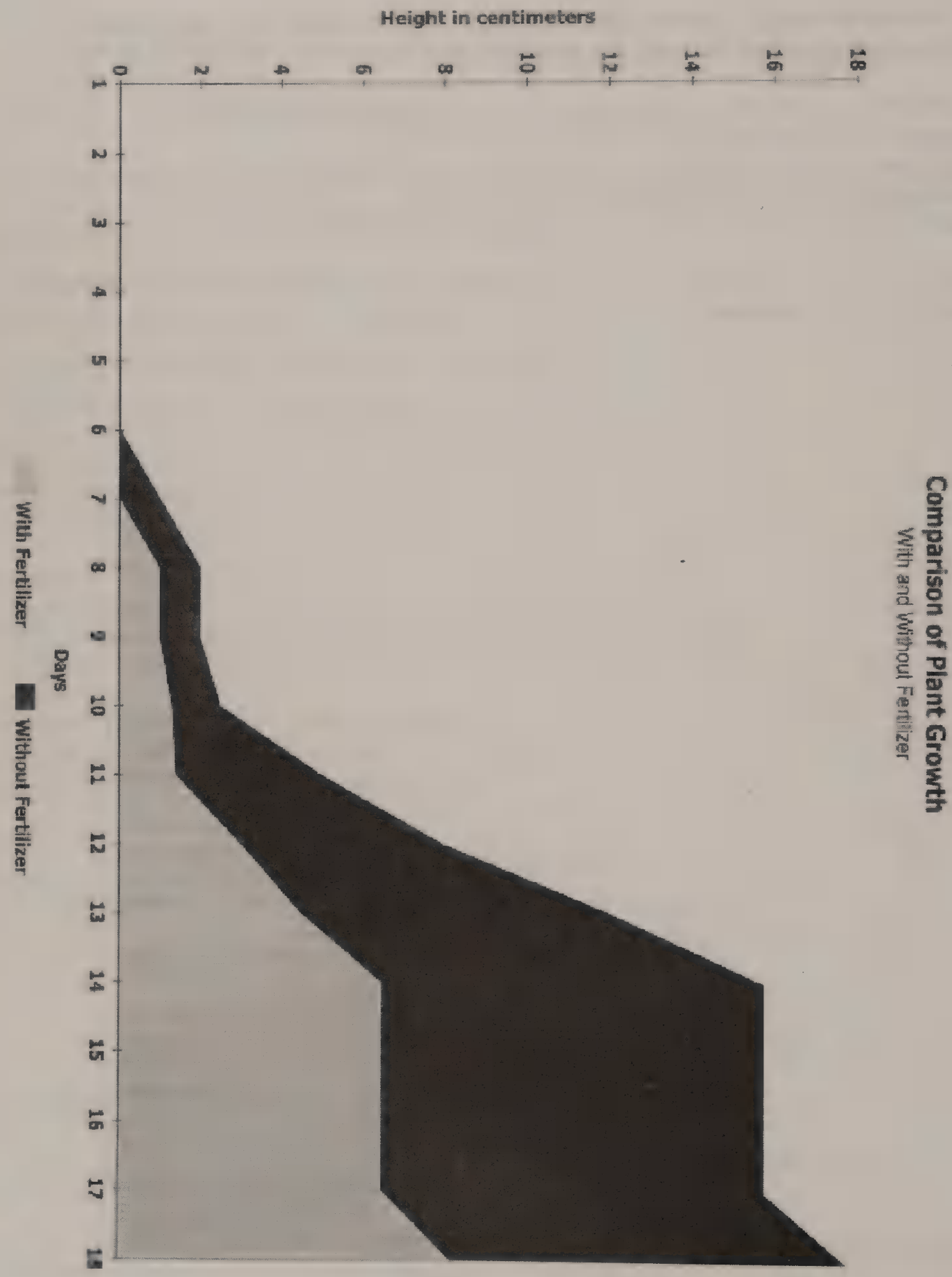
Shown below are a variety of types of graphs/data displays. For each graph, select the response that best represents your familiarity with the graph, and describe the extent of your knowledge for the graph.

a. I have never seen this type of graph before, and I am not sure how to interpret it.
b. I have never seen this type of graph before, but I interpret it as…..
c. I have seen this type of graph before, but I am not sure how to interpret it.
d. I have seen this type of graph before, and I interpret it as…..
e. I have seen and worked with this type of graph before, and I interpret it as…..

In describing your interpretation, explain what the variables are representing, what kinds of information you see in the graph, and anything else you know about this type of graph.

Following this are seven graphs: pie chart (i.e. circle graph), scatter plot, bar graph, stem and leaf plot, box and whisker graph, line graph, and line plot.

Appendix C


Comparison of Plant Growth
With and Without Fertilizer
Height in centimeters
0
2
4
6
8
10
12
14
16
18
Days
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
With Fertilizer
Without Fertilizer

Middle School Students' Conceptual Learning from the Implementation of a New NSF Supported Curriculum: *Interactions in Physical Science*™

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A new National Science Foundation supported curriculum, Interactions in Physical Science™, *was evaluated on students' conceptual change in the twelve concept areas of the national physical science content standard (B) for grades 5-8. Eighth grade students (N=66) were evaluated pre and post on a 31-item multiple-choice test of conceptual understanding developed by the Harvard –Smithsonian Center for Astrophysics. Significant student gains (p<.05, t-test, two-tailed) occurred in all concept areas in the category of* ***properties and changes in properties of matter;*** *for the force concept areas in the category* ***motions and forces;*** *and for the heat transfer and light interactions areas in the category of* ***transfer of energy.*** *Two of the six concept areas in the category of transfer of energy, chemical and nuclear reactions and the sun as a major source of energy, were not addressed in this study. Significant learning gains as item percent correct were typically close to 20%, though effect sizes were small to medium in magnitude (d = 0.3-0.6). Implications of the study for conceptual change curriculum and teaching are discussed.*

The National Science Education Standards (National Research Council [NRC], 1996) includes Content Standards for the broad area of subject matter that should be addressed at each grade band: K-4, 5-8, and 9-12. The subject matter for the physical science standard in grades 5-8 includes twelve bulleted descriptions of the concepts that students should understand in the categories of properties and changes of properties in matter, motions and forces, and transfer of energy (NRC). One approach to teaching physical science concepts for meaningful understanding is through conceptual change teaching.

Conceptual change teaching emphasizes the use of metacognitive skills that help students construct new knowledge and meaning from pre-existing ones, either as gradual step-wise development (Davis, 2003; Hamza & Wickman, 2007; Li, Law, & Lui, 2006) or the resolution of radically conflicting perspectives (Georghiades, 2000; She, 2004). Conceptual change teaching models help students develop scientific understandings through use of a learning cycle that elicits students' prior knowledge and ideas before further exploration and discussion of the phenomenon (Tytler, 2002). Variations of approach exist within a learning cycle, but this format tends to sequence instructional events such that student exploration precedes and supports their effort to explain and make sense of phenomena, with concept discovery or elaboration supported through dialogue among students and with the teacher (Gallagher, 2007). Students must first be aware of their prior understandings of a particular scientific idea and become dissatisfied with their existing conception in light of more plausible ideas before they will modify them (Dykstra, Boyle, & Monarch, 1992; Hewson & Hewson, 1988). As a part of this approach, teachers play a crucial role in eliciting students' ideas and understanding the status they attribute to them – their beliefs and justifications for their ideas – before they can plan further effective instruction (Beeth, 1998). Exploring scientific phenomena through targeted inquiry, particularly discrepant observations and data, supports this change process (Li et al., 2006; Smith, Blakeslee, & Anderson, 1993).

Recently, there have been renewed calls and efforts to apply conceptual change research to pedagogy and learning (Hamza & Wickman, 2007; Settlage & Goldston, 2007). Past middle grades curricula designed with a conceptual change model have been highly effective

in promoting conceptual development and change in students (Muthukrishna, Carnine, Grossen, & Miller, 1993; Smith et al., 1993). A well-designed curriculum supports teachers and students in facilitating this change even when the pedagogical skill needed is complex (Smith et al.).

The *Interactions in Physical Science*™ is a new National Science Foundation supported curriculum that uses a conceptual change teaching model for learning physical science in middle grades (Goldberg, Bendall, Heller, & Poel, 2006). The present study measured the effectiveness of this curriculum for promoting the conceptual understanding of physical science among eighth grade students ($N = 66$) during the spring of 2007. A pre/post test design was implemented assessing learning on the twelve concept areas of the physical science content standard from the National Science Education Standards in grades 5-8 (NRC, 1996).

Addressing Conceptual Ecologies

Science educators have learned that the effectiveness of conceptual change teaching models requires properly sequenced and enacted pedagogy, as well as an understanding of the conceptual ecologies of each student (Beeth, 1998; Park, 2007). Conceptual ecologies include students' past experience, metaphysical beliefs, understanding of the nature of knowledge, affective domain, and epistemological commitments that impact the effectiveness of conceptual change teaching (Park). Interrogating the status that students hold for particular conceptions in order to target further instruction is a first step in taking these ecologies into account (Beeth). Ecologies address why conceptual change models that rely solely on logic and rationality are not always effective in conceptual change. Park found that conceptual ecologies could function as constraints to justifications for reasoning or answers:

> For example, the students made reference to the consistency that their explanations had with other knowledge, past experiences, beliefs rooted in theology, the positions taken by authorities, and/or their subjective evaluations.... It was almost as if the students reasoned, 'I know this piece of knowledge is true because of my experience, my beliefs, the consistency it has with other knowledge, my understanding of learning, my understanding of knowledge, or because my teacher told me so.' (Park, p. 232)

Even when the conceptual change approach is epistemologically coherent for the learner, inadequate attention to the affective domain can lead to student disengagement in learning and inhibit conceptual development (Lee & Brophy, 1996; Park, 2007). Student interest and subsequent involvement in active learning often depends upon the nature of topics studied and the tasks involved, and thus, can be intermittent (Lee & Brophy).

Embedding students' developing ideas within a community of learners that mirrors the functioning of the scientific community can be effective in teaching for conceptual change (Beeth, 1998; Beeth & Hewson, 1999; Thijs, 1992). In such environments students must justify their ideas and status decisions based on negotiation, and learn to make knowledge claims based on evidence, internal consistency, and generalizability as is the case in science. Both students in cooperative teams and teachers work together in the co-construction of knowledge much like scientists do. Instruction is targeted at specific components of the conceptual ecologies emergent from the students, while consistently addressing the nature of scientific knowledge and knowing. This social constructivist approach to conceptual change shows promise in addressing key aspects of students' conceptual ecologies (Beeth & Hewson) and student engagement for learning (Lee & Brophy, 1996).

Context of Curriculum

The *Interactions in Physical Science*™ curriculum follows a conceptual change model while taking a 'community of scientists' approach. This curriculum was chosen for implementation and study because it specifically addressed conceptual change within students' conceptual ecologies. Students share their thinking on conceptual questions within cooperative groups and with the class, provide justifications for their thinking, make predictions for observable outcomes, and negotiate new learning based on evidence (Beeth & Hewson, 1999). This new learning is then applied in new cycles for further conceptual development.

The first unit of the curriculum lays the foundation for working like scientists. Each unit, cycle, and activity in the student textbook is designed following a conceptual change model integrating a highly structured inquiry approach in the exploratory portion of a learning cycle. Students explicitly address prior conceptions on posed key questions related to concepts of study [I THINK/WE THINK] before exploring the concepts

[EXPLORE YOUR IDEAS]. Inquiries support student explorations in gathering specified data or making observations to potentially improve student understanding on each presented idea or concept [MAKE SENSE OF YOUR IDEAS]. The teacher and students collectively negotiate their sense-making before formulating their new learning on an activity's key question [OUR CONSENSUS IDEAS]. Specific materials and resources are provided to support this type of inquiry within each activity. The Appendix lists the topic areas of study (cycles and activities) sequenced within each of seven units. Further details and examples of the curriculum format can be found at: http://www.its-about-time.com/htmls/iaps/iaps.html.

Test Instrument Development

The 31-item multiple-choice test (pre and post) was developed by the Science Education Department of the Harvard-Smithsonian Center for Astrophysics for assessing conceptual understanding in middle grades physical science (Sadler, 1998).[1] The focus of the test items was the National Science Education Standards in 5-8 physical sciences (NRC, 1996). A team of science education experts wrote the test items, based on research examining students' and teachers' conceptual understandings of physical phenomena, and particularly commonly held misconceptions related to properties of matter, forces and motion, and the transfer of energy. Every item drafted by the team was reviewed by a minimum of three scientists actively engaged in research in the area of interest. This review process was iterative, repeating and refining until all reviewers agreed the items they had examined were consistent with current scientific thought. After the scientific review, an independent expert also reviewed every item for readability. The items were then piloted with small samples of students and teachers (n<500). Analysis of the items resulted in the selection of items for field testing. The field test forms each included 5-7 anchor items and several items addressing each standard, varying in difficulty. The field test samples were stratified by census classification of communities (e.g., urban, rural) and region of the U.S. (virtually all states were represented). The field test sample is arguably nationally representative as over 17,000 students and their teachers participated. Data from the field test forms were internally consistent with Cronbach's alpha ranging from 0.7 to 0.9.

This study used a selection of test items drawn from the field test bank that best reflected the range of difficulty and discrimination for each targeted standard, as well as those items that revealed misconceptions most clearly (that is, over 50% of students answering incorrectly chose a single incorrect answer). The data from the study sample were also checked for reliability. The stability of scores (from pre-test to post) and internal consistency of the pre and the post tests were computed using Pearson's r (for stability), and Cronbach's alpha (for internal consistency). All coefficients exceeded 0.70, which, given the sample size, are more than acceptable. In contemporary psychometrics (e.g., Messick, 1995; Moss, Girard, & Haniford, 2006), validity is conceived as a single, unitary characteristic. Simply put, validity is the degree to which scores accurately represent a variable of interest, such as conceptual understanding. The robustness of the process used to develop test items and those items' psychometric characteristics are evidence of the validity of test scores.

Methods

A practical action research perspective where the classroom teacher was principal researcher was taken to evaluate the effectiveness of the *Interactions in Physical Science*™ curriculum on students' conceptual learning (Mills, 2000). The teacher was a science teacher educator of eight years who was on sabbatical to teach eighth grade science in the local school. The previous summer he went through the prescribed one-week training prior to the implementation of the *Interactions in Physical Science*™ curriculum in the spring of 2007. The teacher had three years experience teaching eighth grade students before this study and a total of nine years teaching secondary science, including physical science. He held a current teaching certificate in general science, grades 7-12. The school had a diverse population of students (52% Caucasian, 37% African American, 11% other) and was taught on a block schedule (three classes, each meeting 96-minutes every day) for the semester-long course. As collaborator with this school system on curriculum reform, the professor-teacher worked closely with administration in piloting and evaluating this new curriculum (Fetterman & Wandersman, 2005).

During the first week of school, the teacher's three classes of eighth grade students (N = 66) were administered the pre-test. Between two and four items on the test correlated with each of the twelve concept areas listed under the national standard for physical science in grades 5-8 (NRC, 1996). The Interactions curricu-

lum was implemented as prescribed except students recorded their work in a composition notebook rather than the prescribed student workbook. The first five units of seven included in the curriculum were taught. The units on *Physical Interactions and Phases* and *Chemical Interactions* were not taught due to time constraints. During the last week of the course, students were administered a post-test on the same questions as the pre-test, but in different order. Data were analyzed using a two-tailed t-test for significant changes in correct answers ($p<.05$) on each of the separate 31 items. The effect sizes of the changes were calculated as a *d* statistic with small, medium, and large *d* values corresponding to 0.2, 0.5, and 0.8 respectively (Cohen, 1988). Fifty-nine of the students completed both the pre and post-tests. Test items on the same concept area were placed together in table form.

Results

Results of the pre-post test analysis showed significant increases ($p<.05$, two-tailed, df = 58) in conceptual learning on at least two of two, two of three, or three of four items correlated with seven of the twelve concept areas of the National Content Standard for physical science in grades 5-8 (NRC, 1996) (See Tables).

Data Tables

Twelve concept areas and descriptions from the national science education content standard, physical science grades 5-8, along with test items on each area.

Standard: A substance has characteristic properties, such as density, a boiling point, and solubility, all of which are independent of the amount of the sample. A mixture of substances can often be separated into the original substances using one or more of the characteristic properties.

Table 1

Pre- and posttest means, standard deviations, t-tests, and effect sizes for items addressing motion and position of objects.

Pre-test item (Percent Correct)	*SD*	Post-test item (Percent Correct)	*SD*	*t* value	Df	*p* (2-tailed)	*d* (Effect Size)
0.14	0.346	0.32	0.469	3.02	58	0.004*	0.393
0.17	0.376	0.33	0.475	3.23	58	0.002	0.421

*$p<.05$

Standard: Substances react chemically in characteristic ways with other substances to form new substances (compounds) with different characteristic properties. In chemical reactions, the total mass is conserved. Substances often are placed in categories or groups if they react in similar ways; metals is an example of such a group.

Table 2

Pre- and posttest means, standard deviations, t-tests, and effect sizes for items addressing energy as a property of matter.

Pre-test item (Percent Correct)	*SD*	Post-test item (Percent Correct)	*SD*	*t* value	Df	*p* (2-tailed)	*d* (Effect Size)
0.73	0.449	0.64	0.485	0.85	58	0.398	-0.111
0.12	0.329	0.27	0.449	3.09	58	0.003*	0.402
0.23	0.422	0.42	0.498	2.84	58	0.006*	0.370
0.23	0.422	0.45	0.502	3.21	58	0.022*	0.418

*$p<.05$

Standard: Chemical elements do not break down during normal laboratory reactions involving such treatments as heating, exposure to electric current, or reaction with acids. There are more than 100 known elements that combine in a multitude of ways to produce compounds, which account for the living and nonliving substances that we encounter.

Table 3

Pre- and Posttest Means, Standard Deviations, t-tests, and Effect Sizes for Items Addressing Properties and Changes in Properties of Matter

Pre-test item (Percent Correct)	*SD*	Post-test item (Percent Correct)	*SD*	*t* value	Df	*p* (2-tailed)	*d* (Effect Size)
0.15	0.361	0.33	0.475	3.02	58	0.004*	0.393
0.48	0.504	0.58	0.498	1.00	58	0.321	0.130
0.50	0.504	0.71	0.456	3.59	58	0.001*	0.467

*$p<.05$

Standard: The motion of an object can be described by its position, direction of motion, and speed. That motion can be measured and represented on a graph.

Table 4

Pre- and Posttest means, Standard Deviations, t-tests, and Effect Sizes for Items Addressing Motion and Position of Objects

Pre-test item (Percent Correct)	*SD*	Post-test item (Percent Correct)	*SD*	*t* value	Df	*p* (2-tailed)	*d* (Effect Size)
0.30	0.463	0.33	0.475	0.85	58	0.398	0.111
0.47	0.503	0.32	0.469	-1.73	58	0.088	-0.225
0.67	0.475	0.70	0.463	1.00	58	0.321	0.130

Standard: An object that is not being subjected to a force will continue to move at a constant speed and in a straight line.

Table 5

Pre- and Posttest Means, Standard Deviations, t-tests, and Effect Sizes for Items Addressing Motion and Position of Objects

Pre-test item (Percent Correct)	*SD*	Post-test item (Percent Correct)	*SD*	*t* value	Df	*p* (2-tailed)	*d* (Effect Size)
0.47	0.503	0.76	0.449	3.09	58	0.003*	0.402
0.15	0.361	0.29	0.456	2.42	58	0.019*	0.315
0.56	0.500	0.88	0.329	4.34	58	0.000*	0.565

*$p<.05$

Standard: If more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their direction and magnitude. Unbalanced forces will cause changes in the speed or direction of an object's motion.

Table 6

Pre- and Posttest Means, Standard Deviations, t-tests, and Effect Sizes for Items Addressing Motion and Position of Objects

Pre-test item (Percent Correct)	*SD*	Post-test item (Percent Correct)	*SD*	*t* value	Df	*p* (2-tailed)	*d* (Effect Size)
0.55	0.502	0.82	0.389	4.58	58	0.000*	0.596
0.56	0.500	0.70	0.463	2.13	58	0.038*	0.277

*$p<.05$

Standard: Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways.

Table 7
Pre- and Posttest Means, Standard Deviations, t-tests, and Effect Sizes for Items Addressing Transfer of Energy

Pre-test item (Percent Correct)	*SD*	Post-test item (Percent Correct)	*SD*	*t* value	Df	*p* (2-tailed)	*d* (Effect Size)
0.24	0.432	0.18	0.389	-0.50	58	0.621	-0.065
0.83	0.376	0.89	0.310	1.00	58	0.321	0.130

Standard: Heat moves in predictable ways, flowing from warmer objects to cooler ones, until both reach the same temperature.

Table 8
Pre- and Posttest Means, Standard Deviations, t-tests, and Effect Sizes for Items Addressing Transfer of Energy

Pre-test item (Percent Correct)	*SD*	Post-test item (Percent Correct)	*SD*	*t* value	Df	*p* (2-tailed)	*d* (Effect Size)
0.27	0.449	0.55	0.502	4.49	58	0.000*	0.584
0.20	0.401	0.15	0.361	-1.00	58	0.321	-0.130
0.06	0.240	0.20	0.401	2.42	58	0.019*	0.315

*$p<.05$

Standard: Electrical circuits provide a means of transferring electrical energy when heat, light, sound, and chemical changes are produced.

Table 9
Pre- and Posttest Means, Standard Deviations, t-tests, and Effect Sizes for Items Addressing Transfer of Energy

Pre-test item (Percent Correct)	*SD*	Post-test item (Percent Correct)	*SD*	*t* value	Df	*p* (2-tailed)	*d* (Effect Size)
0.61	0.492	0.70	0.463	1.92	58	0.060	0.250
0.44	0.500	0.26	0.441	-2.46	58	0.017*+	-0.320

*p<.05; +Significant decrease

Standard: In most chemical and nuclear reactions, energy is transferred into or out of a system. Heat, light, mechanical motion, or electricity might all be involved in such transfers.

Table 10
Pre- and Posttest Means, Standard Deviations, t-tests, and Effect Sizes for Items Addressing Transfer of Energy

Pre-test item (Percent Correct)	*SD*	Post-test item (Percent Correct)	*SD*	*t* value	Df	*p* (2-tailed)	*d* (Effect Size)
0.41	0.495	0.44	0.500	0.47	58	0.641	0.061
0.23	0.422	0.21	0.412	-0.47	58	0.641	-0.061

Standard: The sun is a major source of energy for changes on the earth's surface. The sun loses energy by emitting light. A tiny fraction of that light reaches the earth, transferring energy from the sun to the earth. The sun's energy arrives as light with a range of wavelengths, consisting of visible light, infrared, and ultraviolet radiation.

Table 11
Pre- and Posttest Means, Standard Deviations, t-tests, and Effect Sizes for Items Addressing Transfer of Energy

Pre-test item (Percent Correct)	*SD*	Post-test item (Percent Correct)	*SD*	*t* value	Df	*p* (2-tailed)	*d* (Effect Size)
0.41	0.495	0.44	0.500	0.47	58	0.641	0.061
0.23	0.422	0.21	0.412	-0.47	58	0.641	-0.061

Standard: The sun is a major source of energy for changes on the earth's surface. The sun loses energy by emitting light. A tiny fraction of that light reaches the earth, transferring energy from the sun to the earth. The sun's energy arrives as light with a range of wavelengths, consisting of visible light, infrared, and ultraviolet radiation.

Table 12
Pre- and Posttest Means, Standard Deviations, t-tests, and Effect Sizes for Items Addressing Transfer of Energy

Pre-test item (Percent Correct)	*SD*	Post-test item (Percent Correct)	*SD*	*t* value	Df	*p* (2-tailed)	*d* (Effect Size)
0.77	0.422	0.68	0.469	-0.65	58	0.517	-0.085
0.24	0.432	0.29	0.456	0.69	58	0.496	0.090

All three chemical concept areas of *properties of matter*, *chemical reactions,* and *elements* showed significant gains (t =2.84-3.59). Effect sizes were medium (d = 0.4-0.5). Student pre-test scores in the areas of *properties of matter* were very low overall (12-23% correct). Gains occurred on all questions in these three areas except one question in the area on *elements* was not statistically significant (t = 1.00). The concept areas of *heat transfer* and *light interactions* also showed significant gains (t = 2.42-4.49). Effect sizes were small to medium (d = 0.3-0.6). The greatest learning gains on all test items provided occurred for the two concept areas on *force on objects* (t = 2.13-4.58). Effect sizes were small to medium (d = 0.3-0.6). Student learning gains that were significant for each question on the test showed increases between 14% and 32% on correct responses with most gains close to 20%.

Students did not improve significantly in their understanding in the areas of *motion and position of objects*, *energy as a property of matter*, *transference of electrical energy*, *transference of energy in chemical and nuclear reactions*, and *the sun as an energy source*. Further study of pre-test scores showed that students entered the course with high levels of conceptual understanding on specific test items which also showed gains on the post-test that were not significant. These items were on concept areas including *motion and position of objects* (one item mean = 0.67 pre), *energy as a property of matter* (one item mean = 0.83 pre), *transference of electrical energy* (one item mean = 0.61 pre), and *the sun as an energy source* (one item mean = 0.77 pre).

Low pre and post-test results (p >.05, two-tailed) for all test items on a concept area occurred on *energy transfer for chemical and nuclear reactions*. This concept area included in Units 6 and 7 was not taught due to time constraints.

Conclusions

The *Interactions in Physical Science*™ curriculum, Units 1-5, supported significant gains (p <.05, two-tailed, df = 58) in students' conceptual understanding on seven of the twelve concept areas of the National Science Education Content Standard for physical science in grades 5-8 (NRC, 1996). These gains were particularly evident on questions involving the physical and chemical nature of matter, behavior of forces on objects, transfer of heat energy, and light interactions.

The standard concept area of *energy transfer for chemical and nuclear reactions*, found in Units 6 and 7, was not taught due to time constraints. Also, the standard concept area of *the sun as an energy source* was not evident in this curriculum. Therefore, based on this curriculum and what was taught, significant gains in student learning with effect sizes from small to medium occurred on seven of ten concept areas for the physical science standard. Although gains on the seven concept areas were significant, students still marked correct answers to items on the *properties of matter* area less than 34% of the time.

Limitations on Scope of Study

The 31-item, multiple-choice test of conceptual learning in middle grades physical science only included 2-4 items on each of the twelve concept areas of the physical science standard. Broad generalizations about the depth and breadth of student learning on each concept area cannot be made from this test due to the limited number of items and the forced-choice format. Also, for this population of students, effect sizes were small to medium on significant results. Though significant gains in student learning occurred on the majority of standards taught, the strength of those gains were limited. Significance alone may be misleading to readers because the magnitude of learning gains in this study never reached the strong level. Lastly, this study as action research in one teacher's classroom is limited in scope and should not be generalized to the greater population of eighth grade students (Mills, 2000). Further extensive quasi-experimental studies need to be conducted to validate the impact of this curriculum on student learning and conceptual change in the greater population.

Implications

The conceptual change learning cycle model used in the *Interactions in Physical Science*™ curriculum was effective in students' conceptual change for seven out of ten of the concept areas that were addressed in this study. This study supports the 'community of scientists' approach to addressing students' conceptual ecologies for conceptual change (Beeth, 1998; Beeth & Hewson, 1999; Park, 2007; Thijs, 1992). Also, results from this study support previous research studies showing that curricula and teaching designed for conceptual change in the middle grades are effective (Muthukrishna et al., 1993; Smith et al., 1993). However, in this study the strength of learning gains only ranged from small to medium. Though significant the magnitude of positive change was not as great as expected. Regarding the difficulty with energy concepts, this curriculum addressed wave and mechanical energy transfer between objects in Unit 2, and heat energy transfer in Unit 4. However, for the students in this study their understanding of concepts on energy as a property of matter did not improve statistically. Energy encompasses particularly abstract and difficult concepts for middle grades students to understand, and likely needs to be addressed further in student learning and future curricula.

The results of this study show the approximate percent of student gains on conceptual questions was no higher than 32%, with most gains close to 20%. This occurred regardless of percent correctness on the pre-test, including particularly low pre-test scores in some areas, and was the likely cause of the lower effect sizes. It appears that students' conceptual change in this study when present made an impact on less than 33% of the students, demonstrating once again that conceptual change is difficult to achieve (Dykstra et al., 1993). Based on this study it is not possible to know if student learning was radical conceptual change or incremental change. Further research is needed on whether the development of student prior conceptions leads to conceptual change, and the 'tipping point' in choosing correct test responses (Davis, 2003; Hamza & Wickman, 2007; Li, et al., 2006), or whether change in such students was more radical (Georghiades, 2000; She, 2004). Such knowledge would help provide guidance in the type of conceptual change model to use for maximum effectiveness.

This study further supports the premise that desired outcomes in conceptual change will take time, even with effective curricula and teaching, and that teachers should use diagnostic tools such as conceptual tests to know where to spend more time and effort in their curriculum and teaching. Meeting the goal of understanding in physical science based on the physical science content standard in middle grades (NRC, 1996) will also require an integrated science curricula where concepts are addressed over time in more than one course for continued gains in student learning.

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RESEARCH IN
the classroom

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Student Learning about Twelve Features of the Nature of Science

Five Teacher Leaders organized a study regarding two of their sections of 8-9th grade science. One section was the experimental section where twelve constituents of the Nature of Science (NOS) were used as an added consideration to activities, discussions, projects, and focus for all aspects of science content. The control section was a typical one where STS approaches were used without any conscientious efforts to add appropriate NOS considerations. Significant differences were found regarding student improvement and understanding of the twelve NOS constructs that were utilized; no such differences were noted in the control sections for the five teachers.

The purpose of this report is to share the research results produced by five middle school science teachers regarding changes in student perceptions of twelve features characterizing the Nature of Science (NOS). The twelve ideas used to define science were drawn from Aikenhead, Ryan, and Fleming (1989) and Aikenhead and Ryan (1992), which focused on student understanding and perceptions of science and technology involving a huge sampling of students across Canada. Aikenhead developed a 116 page questionnaire that included nearly a dozen possible reactions to illustrate ways students commonly misunderstand science. This effort in Canada has prompted renewed interest in student visions of science in K-12 classrooms in the U.S. A focus on NOS has become a facet of content for K-12 science as included in the National Science Education Standards (NSES) and further defined as one important area of content in the final version published by the National Research Council (1996). The Nature of Science became the sixth domain for teaching and assessment as proposed by McCormack and Yager (1989) and used in the Iowa Chautauqua project and the Scope, Sequence, and Coordination project of the National Science Teachers Association (NSTA). The five teachers were leaders in both Iowa reform initiatives.

The twelve features of science chosen by the five teachers involved with this study include seeing science as:

1. Questioning and exploring nature;
2. Offering explanations of the objects and events encountered;
3. Testing possible explanations;
4. Recognizing the tentativeness of science constructs;
5. Understanding the theories which illustrate the Nature of Science;
6. Realizing that science explanations change over time;
7. Beginning with personal creativity and imagination;
8. Being affected by social/cultural factors;
9. Requiring the use of science constructs in new contexts;
10. Important for the collection of multiple examples of evidence to support given explanations;
11. Inviting the improvement of arguments used to support explanations;
12. Requiring the interactions with others (including experts in person and via their writings) concerning the explanations accepted.

Methodology

The five teachers were important members of the professional development activities of the state. They were involved each year with at least one action research project as they participated and led workshops that were offered as part of the NSTA Chautauqua effort and the NSTA Scope, Sequence, and Coordination project. There have been twenty teacher leaders involved with implementing NSES visions – some as early as 1983. The five teachers involved with this study were familiar with NSES – its organization, development, and stated goals. They looked for new questions about teaching and learning and new frameworks that include use of the social sciences of science and the emerging Science/Technology/Society (STS) research efforts (AAAS, 1990; Blunck & Yager,1990).

There was much debate about the specific twelve features of science initially selected for the study in the five schools involved with the NSTA SS&C projects. All had been involved in collaborative efforts across their own districts; all had strong support from their principals and the parents of their students.

Two sections were selected by each teacher – one where the typical societal issues were used as organizers – but with no special consideration of the twelve features of the Nature of Science selected for emphasis in a class utilizing the STS approach. The second section became the experimental section where each of the 12 features of science where analyzed and used regularly (often at the end of each week) as a complement to the extension of the STS efforts in the school. The defining features of STS were described by NSTA as:

1. Student identification of problems with local interest and impact;
2. The use of local resources (human and material) to locate information that can be used in problem resolution;
3. The active involvement of students in seeking information that can be applied to solve real life problems;
4. The extension of learning going beyond the class period – the classroom, the school;
5. A focus upon the impact of science and technology on individual students;
6. A view that science content is more than concepts which exist for students to master on tests;
7. An emphasis upon process skills which students can use in their own problem resolution;
8. An emphasis upon career awareness – especially careers related to science and technology;
9. Opportunities for students to experience citizenship roles as they attempt to resolve issues they have identified;
10. Identification of ways that science and technology are likely to impact the future;
11. Some autonomy in the learning process (as current issues are identified and used). (NSTA, 2008, p. 242)

Both sections were identical as revealed by gender balance, ability levels, socio-economic levels, and time of day for science. Counselors reviewed the two class sections and confirmed the similar study organizers and instructional foci; certainly the curriculum structure was the same. The only difference was the conscientious efforts of a consideration of the twelve features of science used to define an added focus on NOS used in the experimental class sections of the five teachers.

A rubric was constructed and used as the instrument to indicate student understanding of the 12 NOS in the two sections which were both taught using STS teaching approaches but with one considering NOS features characterizing the content, activities, projects that comprised the instructional strategies used in all class sections. Conscientious efforts were made in the experimental section to illustrate the 12 features of science while no similar efforts were undertaken with students in the control section. This included weekly sessions where examples of NOS for all class activities were discussed and related to the NOS features illustrated. Since STS means dealing with current, local, and personally relevant themes/problems, no textbook or curriculum guides were used with students in either section. But, the control sections included some use of a textbook and teacher plans that provided the focus for the prescribed content while pursuing personal and/or social issues and their resolution as a primary feature of STS teaching. The five teachers certainly were anxious not to disadvantage the students in the non-NOS sections. Students in both sections experienced STS instruction and a focus on the Essential Features of Inquiry as well as elaborated in the "Inquiry and the National Science Education Standards" monograph (NRC, 2000, p 29). These five Essential Features include: 1) Learner engages in scientifically oriented questions; 2) Learner gives priority to evidence in responding to questions; 3) Learner formulates explanations from evidence; 4) Learner connects explanations to scientific knowledge; and 5) Learner communicates and justifies explanations.

This list is very similar to the definitions of science itself as arising from Simpson's definition (1963). This definition was used often in STS classrooms generally. The difference between the teachings in the two sections was confined to the consideration of the 12 NOS features teachers used for this action research effort. Teachers (as well as students) had access to the twelve NOS features – where both teachers and students looked for connections to illustrate their studies as being related to specific NOS features.

Results

Table 1 is a report of the semester long research effort that five 8th and 9th science teachers undertook for a full semester that characterized STS teaching. The twelve features of NOS were used as part of post-test measures to determine student perceptions of each.

Table 1

Changes in Pre and Post Ideas Concerning the Nature of Science Between Students Enrolled in Regular STS Sections and One Where NOS Features were Emphasized and Considered by Five Iowa Middle School Science Teachers

Features of Science Considered	NOS Emphasis		No Use of NOS	
	Pre	Post	Pre	Post
1. Questioning and Exploring Nature	3.4	15.4	3.5	4.1
2. Offering Possible Explanations of Objects and Events	5.6	16.8	6.1	7.2
3. Testing Possible Explanations for Validity	12.3	18.1	11.8	12.3
4. Tentativeness of Science Constructs	3.6	17.3	2.6	8.1
5. Nature and Use of Science Theories	10.1	18.1	9.8	10.7
6. Science Explanations Change Over Time	5.2	15.3	4.9	5.8
7. Creativity and Imagination Important for Science	3.1	16.2	4.2	5.3
8. Effects of Societal and Cultural Features	2.4	13.1	2.9	3.4
9. Using Science Constructs in New Contexts	2.6	15.4	3.1	3.1
10. Collecting Multiple Examples of Evidence to Support Explanations	3.6	16.8	4.1	5.2
11. Improving Arguments Used to Support Explanations	3.4	17.2	3.7	4.0
12. Importance of Sharing Explanations in person and/or Via Writings	8.1	16.2	9.8	8.1

The rubric consisted of a scale with a maximum score of twenty as follows:

How would you rate the importance of each construct in terms of your own understanding of the nature and meaning of science?

Analyses revealed that averages for the 20+ students in each section initially were almost exactly the same (no significant differences) as measured by the pretests where impressions of NOS arose from science experiences in earlier grades. Further, the reports from students in the non-NOS sections remained largely unchanged regarding the twelve perceptions of NOS. Apparently use of the typical class organizers and teacher directed protocols (even with STS approaches) are ineffective for increasing knowledge and skills regarding the twelve facets of NOS chosen for focus by five the teachers in the study.

However, there are significant differences for students taught by all five teachers with the students enrolled in their NOS sections between pre- and post-test perceptions. There were no observable differences concerning these results among the students in the five sections. Efforts continue to examine the results with each teacher and across all five school districts and at other grade levels. Some of those differences were reported with other technical reports of the effectives in all six assessment domains in all twenty SS&C schools (Yager & Weld, 1999) and final report concerning results of SS&C to NSF (Yager, Liu, & Varrella, 1993)!

Discussion

Individual teachers selected additional features from Aikenhead's VOSTS research that extended their research with students in multiple sections for the second semester of their year-long life science courses – usually in sections other than the two involved with the results reported in this study. Similar results were recorded. Teachers often tried other samples of the VOSTS items to extend their own specific research interests further. Such teacher "buy-in" was important and explains the positive results regarding student understanding of the NOS.

Caution is recommended in using the results reported for this study since the five teachers were among the most successful with STS and admittedly wanted to look specifically at strategies that would

show advances regarding students understanding of the twelve NOS areas. The five teachers were the most knowledgeable of the NSES and most interested in a focus on NOS where results could be demonstrated as superior in the Worldview Domain. All were quick to help students experience all five facets of the Essential Features of Inquiry in both sections for the five teachers. All were anxious to collect the data to share with students, to analyze differences, to encourage use and understanding of NOS, and to note how this construct influenced daily living. Students, other teachers, school administrators, parents, and other school leaders were asked to review the results and to discuss their significance. Science teaching was seen as a focus on student construction of meaning individually; science was also seen as a collaborative effort; and learning was seen as something people do that is more than being attentive or merely accepting what teachers, parents, and textbooks say and what results could be noted with use of weekly and nine week examinations. Qualitative data were also used to provide an added focus on NOS features which improved student understanding in this domain. Often real learning does not occur until students do it themselves and until they can apply the learning in completely new contexts. The focus on NOS produced added evidence of how STS strategies can be applied specifically for learning about NOS, and how students can learn to discuss such features, usually considered only peripherally in most K-12 science classrooms.

Understanding of some NOS aspects may be important because it helps students experience real science. Science in K-12 settings is seen as vitally important for meeting the four goals framing the NSES. These are:

1. Effecting the daily lives of every student;
2. Enabling graduates to assist in resolving societal problems;
3. Improving economic productivity and career awareness;
4. Providing real experiences with the whole sequence of activities called science and/or inquiry.

These are the four goals central to the NSES for all science teachers and all K-12 schools (NRC, 1996). All too often, however, with the lack of specific attention to NOS, a consideration of all eight facets of content prescribed by the NSES (NRC, 1996) , and/or making the needed changes in the teaching envisioned in the NSES (NRC, 1996), students typically do not improve with respect to understanding better the specific tenants of science. In typical classrooms students merely do what they are told and recite what they are told via lectures and/or from readings from textbooks (Brandwein, 1983). STS, however, demands work on real problems and projects devoted to school and community betterment. These are important goals and attributes that by themselves do not improve student understanding of science—and recognizing them as a part of NOS. The focus for the students in the regular STS sections in this study was often on the traditional concepts and processes that are also the features of traditional science classrooms. But, students in STS classrooms learn to apply these concepts and skills to deal with local issues, personal interests, and current concerns. Too many leaders assume that NOS considerations can be handled in the same ways, i.e., by transmission from teachers to students. This study is being replicated in other states and nations, especially where there are persons concerned with the failure to portray science accurately and to encourage students to experience firsthand the real Nature of Science! This focus was central to studies characterizing the major symposium of the 2008 International Organization of Science and Technology Education (IOSTE) which met in September 2008 in Izmir, Turkey (13th IOSTE Symposium).

Summary and Conclusions

Several observations indicate the results of this study undertaken by five experienced STS teachers with special interest in the Nature of Science. Twelve features were chosen to illustrate the Nature of Science for a semester long study in one class section.

Teachers for students in one section of an STS focused curriculum chose to consider an added focus on NOS. More learning regarding NOS was achieved by students in classrooms where teachers worked to promote this added benefit. When teachers related specific traditional NOS to the on-going STS instruction, the students with NOS foci saw science as:

1. Questioning and exploring nature;
2. Offering explanations of the objects and events encountered;
3. Testing possible explanations;
4. Recognizing the tentativeness of science constructs;
5. Understanding better the Nature of Science theories;
6. Realizing that science explanations change over time;
7. Illustrating the power of creativity and imagina-

tion as important features of science;

8. Being influenced by social/cultural factors influence science;

9. Requiring the use of science constructs in new contexts;

10. Necessitating the collection of multiple examples of evidence to support explanations;

11. Improving arguments used to support explanations;

12. Requiring the interaction of others (including experts in person and via their writings) concerning the explanations accepted.

The results are not unexpected – but do illustrate the importance of precise goals and attention to them. Perhaps students need more direct experience with specific features of NOS before learning in this domain is accomplished fully. Students who discuss and relate NOS features in the context provided by STS improve in their understanding over students where specific attention is not provided.

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Dr. S. Wali Abdi, 54, died October 23, 2008, after a long battle with leukemia. He served the School Science and Mathematics Association for over 15 years as editor of the Book Review section of the School Science and Mathematics Journal. Dr. Abdi was a professor of science education in the College of Education at the University of Memphis, which he joined in 1993. He is the recipient of numerous awards including: The University of Memphis Alumni Distinguished Teaching Award; Science Educator of the Year Award for Higher Education presented by Tennessee Science Teachers Association; and The Outstanding Teacher of the Year Award presented by Memphis Organization of Science Teachers. Dr. Abdi also received The Outstanding Award of the Year for Teaching and for Service in the College of Education. He is survived by his wife, Angela; children, Arrin (Erica), Michelle (Lizann), Carol (Cory) McCullough; and four grandchildren.

Science Safety in the Community College
Authors: J. Summers, J. Texley, and T. Kwan

National Science Teachers Association Press
NSTA Press
1840Wilson Blvd.
Arlington, VA 22201

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Reviewer: Lloyd H. Barrow
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Columbia, MO 65203

Science Safety in the Community College is the fourth in a series to provide direction to K-14 teachers of science as they implement the recently adopted NSTA Safety Position Statement. This resource address unique aspects of teaching at a community college including diverse ages of adult learners, facilities guidelines, part-time faculty, generic aspects of safety, English as a second language, and awareness that many students lack science understanding and aspects associated with safety (chapter 2).

The first chapter provides an overview of the resource plus ways to implement safety via of syllabus and maintaining explicit records of your use of safety procedures. Chapter 3 utilizes NSTA facilities guidelines related to promoting safe laboratory operations. Safe storage of chemicals and various laboratory equipment is the focus of the chapter 4. Chapters 5-9, with extensive sidebars, has separate chapters devoted to living organisms, chemistry, earth and space science, physics and field studies. Each of the chapters has extensive web based resources plus SciLinks related topics. The final two chapters focus upon general aspects of safety related to teaching in community college laboratories where the four P'S – prepare, plan, parent, and protect are intended to broaden readers understanding of safety.

Each chapter has descriptive headings, vignettes, and extensive web resources plus SciLinks associated with each topic. An extensive glossary, disposal of chemicals, NSTA safety position statement and index are separate appendices. Readers can focus upon chapter related to their discipline or read it from cover to cover. The author's stress their orientation that …"safety is more than a set of rules. It's a state of mind"(p. viii). The concluding chapter has a series of major bullets associated with each of the earlier eleven chapters. Faculty with limited time should read the concluding chapter first, and then decide which chapter(s) to read next.

The authors are veteran NSTA leaders although; they did not list community college experiences in their biographies. National safety experts reviewed the manuscript. Even though the resource was intended for community college faculty, the book will also be applicable to undergraduate science faculty and teaching assistants.

PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to: Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel; or fax to:972-86-477-648. Questions concerning proposals and/or solutions can be emailed to: eisenbt@013.net. Solutions to previously stated problems can be seen at: ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before March 15, 2009

5044: *Proposed by Kenneth Korbin, New York, NY.*

Let N be a positive integer and let

$$\begin{cases} x = 9N^2 + 24N + 14 \text{ and} \\ y = 9(N+1)^2 + 24(N+1) + 14. \end{cases}$$

5045: *Proposed by Kenneth Korbin, New York, NY.*

Given convex cyclic hexagon ABCDEF with sides

$$\overline{AB} = \overline{BC} = 85$$
$$\overline{CD} = \overline{DE} = 104 \text{ and}$$
$$\overline{EF} = \overline{FA} = 140.$$

Find the area of $\triangle BDF$ and the perimeter of $\triangle ACE$.

5046: *Proposed by R.M. Welukar of Nashik, India and K.S. Bhanu and M.N. Deshpande of Nagpur, India.*

Let $4n$ successive Lucas numbers $L_k, L_{k+1}, \cdots, L_{k+4n-1}$ be arranged in a $2 \times 2n$ matrix as shown below:

$$\begin{matrix} 1 & 2 & 3 & 4 & \cdots & 2n \end{matrix}$$
$$\begin{pmatrix} L_k & L_{k+3} & L_{k+4} & L_{k+7} & \cdots & L_{k+4n-1} \\ L_{k+1} & L_{k+2} & L_{k+5} & L_{k+6} & \cdots & L_{k+4n-2} \end{pmatrix}$$

Show that the sum of the elements of the first and second row denoted by R_1 and R_2 respectively can be expressed as

$$R_1 = 2F_{2n}L_{2n+k}$$
$$R_2 = F_{2n}L_{2n+k+1}$$

where $\{L_n, n \geq 1\}$ denotes the Lucas sequence with $L_1 = 1, L_2 = 3$ and $L_{i+2} = L_i + L_{i+1}$ for $i \geq 1$ and $\{F_n, n \geq 1\}$ denotes the Fibonacci sequence.

5047: *Proposed by David C. Wilson, Winston-Salem, NC.*
Find a procedure for continuing the following pattern:

$$S(n,0)=\sum_{k=0}^{n}\binom{n}{k}=2^n$$

$$S(n,1)=\sum_{k=0}^{n}\binom{n}{k}k=2^{n-1}n$$

$$S(n,2)=\sum_{k=0}^{n}\binom{n}{k}k^2=2^{n-2}n(n+1)$$

$$S(n,3)=\sum_{k=0}^{n}\binom{n}{k}k^3=2^{n-3}n^2(n+3)$$

$$\vdots$$

5048: *Proposed by Paolo Perfetti, Rome, Italy.*
Let a, b, c be positive real numbers. Prove that

$$\sqrt{c^2(a^2+b^2)^2+b^2(c^2+a^2)^2+a(b^2+c^2)^2}\geq\frac{54}{(a+b+c)^2}\quad\frac{(abc)^3}{\sqrt{(ab)^4+(bc)^4+(ca)^4}}.$$

5049: *Proposed by José Luis Díaz-Barrero, Barcelona, Spain.*
Find a function $f:\Re\to\Re$ such that

$$2f(x)+f(-x)=\begin{cases}-x^3-3, & x\leq 1,\\ 3-7x^3, & x>1.\end{cases}$$

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Enough information to enable replication (quantitative)

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IN THIS issue

Research Articles

Authentic and Simulated Professional Development: Teachers Reflect What is Modeled

Nikki Hanegan, Kelley Friden, C. Riley Nelson

Science is a dynamic discipline, representative of the nature of science. Yet, young science students continue to think everything is already discovered. In this study, we examine why students are not actively doing science. From professional development to student engagement, how are classrooms and students changing as we increase teachers' content knowledge? Teaching practices modeled in professional development can change what occurs in the classroom. Our study was designed to probe differences in two different types of professional development programs both focused on content knowledge. We found that what is modeled by the professional developers has a profound effect on the direction of the classroom.

Development of a Community of Science Teachers: Participation in a Collaborative Action Research Project

Xavier Fazio

This article presents a study exploring the beliefs, knowledge, and practices of four middle and secondary science teachers participating in a collaborative curriculum action research project. Using a case study methodology, the views and practices of these teachers were described and analyzed as they investigated novel ideas about scientific inquiry and nature of science, critically examined their practice, and implemented and reflected upon modified curricular practices. Findings indicated that by the end of the study, all participants had enhanced their views of scientific inquiry and nature of science, and the collaborative group evolved as a community of teachers. Wenger's (1998a) community of practice theory provided a useful framework to describe and analyze the experiences of these science teachers. Implications for the professional development of science teachers and the compatibility between a community of practice and collaborative action research projects are presented.

Preparing Pre-Service Teachers to Teach Mathematics in Inclusive Classrooms: A Three-Year Case Study

Dolores Burton, Darra Pace

Federal and state regulations mandating inclusion of students with disabilities in general education classes have made it essential to create pathways for pre-service teachers to develop skills to teach content to diverse groups of students. The study uses a framework suggested by the relationship between teacher attitude and teacher behavior (Fullan, 1982), teacher beliefs and practice, and self-efficacy and behavioral change (Bandura, 1977). The purpose of the study was to examine changes, if any, in three cohorts of general education teacher candidates' (n=13, n=8, n=5) attitudes toward teaching mathematics to students with disabilities after participating in focused instructional experiences which provided both information and vicarious positive teaching activities in special education. Data collected included pretest and posttest scores for each of the three cohorts and journal entries. Little or no change in attitude towards students with disabilities and mathematics, and efficacy to teach students with disabilities was observed for the year one and year two cohorts. In the third year the modules were combined with a structured field experience. The data collected from the third year cohort suggested a positive trend in attitude as measured by the survey data and field experience journal data. Future study with larger samples is needed.

Research in the Classroom

Understanding the Affects of Audience on Mathemtaical Writing

Byung-In Seo

This study formally explored how high school students addressed audience when they wrote mathematically. Student explicated the solving of a mathematics problem to their mathematics teacher and their English teacher. This study showed that students did change the style and language of their mathematical writing as their audience changed. It adds knowledge and support to current ideas of teacher presentation during routine daily instruction. Also included are implications this information may have on mathematics education.

Authentic and Simulated Professional Development: Teachers Reflect What is Modeled

Nikki Hanegan
Brigham Young University

Kelley Friden
Oregon City School District

C. Riley Nelson
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Science is a dynamic discipline, representative of the nature of science. Yet, young science students continue to think everything is already discovered. In this study, we examine why students are not actively doing science. From professional development to student engagement, how are classrooms and students changing as we increase teachers' content knowledge? Teaching practices modeled in professional development can change what occurs in the classroom. Our study was designed to probe differences in two different types of professional development programs both focused on content knowledge. We found that what is modeled by the professional developers has a profound effect on the direction of the classroom. This matched controlled study found that teachers reflect the teaching practice modeled by professional developers through their individual classroom teaching practices. A significant difference was found in cognitive activities and questioning skills between teachers in a professional development program modeling authentic inquiry versus the teachers in a professional development modeling simulated inquiry. While both groups increased the amount of overall inquiry used in the classroom, students whose teachers were in authentic inquiry professional development were engaged in higher cognitive activities and questioning skills. If students are engaged in dynamic classrooms, searching for answers to students' questions, perhaps they will understand that science is a dynamic discipline.

Scientific inquiry has emerged as an important topic in science education, whether the conversation is about science literacy, standards, instructional strategies or basic science content (Llewellyn, 2005; National Research Council [NRC], 1996; Tolman, 2001). Inquiry, a fundamental component of science education, increases student retention of knowledge and should be used frequently in the classroom (AAAS, 1993; Gabel, 2003; NRC, 1996).

The different types of classroom inquiry span a five-level hierarchy: 1) In the lowest-level students perform such low-cognitive-level tasks as reading, writing, or limited hands-on activities. 2) In simulated inquiry, teachers replicate scientific studies using alternative tools like computers. 3) Teacher-guided inquiry allows teachers to pose a question and present students with a prescribed procedure for investigation. Typically, teachers will incorporate simulated inquiry with this approach, so the second and third approaches sometimes overlap. 4) In student-guided inquiry the teacher presents a question and students design or select their own procedures to answer it. 5) Authentic inquiry, the highest level, allows students to design their own problems and propose their own solutions. The teacher then acts as a resource and facilitator for the student-driven investigation (Ibe & Deutscher, 2004; NRC, 2000b; Rham, Miller, Hartley & Moore, 2003; Thompson & Parrott, 2003).

Teachers are exposed to inquiry approaches during their pre-service programs at the university level and through professional development programs after they graduate. While professional development courses are designed to help teachers learn their subject in greater depth and to implement effective teaching practices, most teachers do not apply their professional development learning experiences in the classroom (Hanegan & Nelson 2002; Roth, McGinn & Bowen, 1998). To integrate new knowledge gained from professional development into their classroom practices, teachers need field work, guidance, and communication from their professional development coordinators (Fraser-Abder, 2002; Handelsman, et al., 2004; VanDriel, Beijaard & Verloop, 2001). Ongoing professional development should provide necessary resources and an outside perspective for follow-up sessions that encourage further learning (Fraser-Abder).

Teachers learn to implement inquiry by attending a professional development program that models and

practices inquiry (Hanegan & Nelson, 2002; Yager, Abd-Hamid, & Ackay, 2005). Effective professional development exposes teachers to professional developers, including professors and researchers, who work with teachers to improve content knowledge, simultaneously with pedagogical specialists, who enhance teaching practices and model strategies teachers could use with their students (Nelson & Hanegan, 2003). Effective professional development programs build from the teachers' current knowledge levels (both content and pedagogical), provide ample time for in-depth investigations, collaborative work, and reflection that connects clearly with teachers' other professional development experiences and activities (Fraser-Abder, 2002; Klentschy, 2005).

This study examined two types of inquiry, authentic and simulated, to find out whether different levels of inquiry in professional development programs affect the classroom implementation of inquiry practices. The participants in this study consisted of 10 secondary biology teachers and their classrooms. In this study, simulated inquiry involved computer-based representations or other curriculum material that simulates scientific investigations.

This study also examined which type of inquiry creates higher level cognitive activities and questioning skills in both teachers and students by exploring the following criteria: 1) questioning skills of teachers and students, 2) teacher-to-student interaction, 3) teachers' pedagogical practices, and 4) teachers' understanding of inquiry. Three research questions drove this study: 1) Do the two programs produce differences in the questioning skills of teachers and students? 2) How do participants in the two programs differ in teacher-to-student interactions? 3) Do the programs produce differences in teachers' pedagogical practices?

Literature Review

The literature can be divided into three categories: 1) the value of inquiry, 2) the effectiveness of professional development, and 3) the effects of good questioning skills in the classroom.

The Value of Inquiry

Inquiry has become a valuable tool in science education (Krueger & Sutton, 2001). In science classrooms authentic inquiry allows students to formulate questions and then seek possible responses to those questions (NRC, 2000b). Many studies have looked at the effects of inquiry. Tolman (2001) reported that a comparison of all inquiry techniques used in the 1993-94, 1994-95, and 1995-96 school years confirmed that non-science major students taking the inquiry-based Natural Science Inquiry courses at Portland State University improved their appreciation of science and its relevance to their lives in contrast to students in standard lecture-format science courses.

Other research used multiple choice tests, constructed response questions, and teacher questionnaires to identify teaching practices that lead to higher science achievement which allowed individuals to "do science" and to use their active sensory perception (Howard Hughes Medical Institute, 2005; Koballa, 1986; Krueger & Sutton, 2001; NRC, 2000a; Siebert & McIntosh, 2001; Tolman, 2001; VonSecker & Lissitz, 1999). Innovative college and university teaching faculty have moved from showing students what it is like to do science towards presenting them with real problems and asking them to come up with their own solutions (Dubner, 2003; Howard Hughes Medical Institute, 2005).

Inquiry has five characteristics for student learners: Learners 1) are engaged by scientific questions, 2) value evidence, 3) formulate explanations from evidence, 4) evaluate explanations, and 5) communicate and justify their proposed explanations (Krueger & Sutton, 2001; NRC, 2000b; Seibert & McIntosh, 2001). In comparison, Chinn and Hmelo-Silver (2002) found three key actions of authentic inquiry: 1) incorporate complex inquiry tasks based in practical scientific work, 2) investigate reasoning strategies that are effective on complex tasks, and 3) implement instructional techniques that help students learn effective reasoning strategies.

In effective inquiry, students become researchers. Even so, there is no one way to implement inquiry in the classroom. Investigations can be teacher-structured leading students toward known outcomes or can be open-ended using unexplained phenomena (NRC, 2000b). In certain learning circumstances, however, different types of inquiry are more effective than others. Learning a scientific technique, for example, may benefit from guided inquiry, while open inquiry may encourage cognitive development, scientific analysis and innovative use of techniques (NRC, 2000b). By creating classroom tasks and conditions that encourage students to express their thoughts, teachers can actively ascertain students' views and help them build deeper and more formal scientific understanding from their initial conceptions (NRC, 2000a). Overall, authentic inquiry emphasizes the ability to apply, rather than to

memorize facts (Tolman, 2001). A classroom question strong and rich enough to drive inquiry generates students' "need to know" and stimulates additional questions addressing the "how" and "why" of an event (NRC, 2000b).

Effectiveness of Professional Development

As important as it is for teachers to understand inquiry, develop their proficiency in conducting inquiry, and learn science concepts through inquiry, they also need to learn how to teach using and fostering inquiry (Nelson & Hanegan, 2003). Professional development can model such teaching by extending teachers' own inquiries into the implications for their teaching or by helping teachers teach through inquiry (NRC, 2000b). Professional development that focuses on improving teaching through inquiry provides teachers with one-on-one experiences, such as coaching; joint work, such as study groups; and job-embedded learning experiences, such as action research; different from those offered by more traditional college courses or in-service workshops (NRC, 2000b).

Some professional development programs, however, do not model what they teach. They are not learner centered, knowledge centered, assessment centered, or community centered. Teachers go to these programs hoping to learn something new but return to their classrooms confused. Effective professional development experiences, on the other hand, model strategies teachers can employ with their students. For example, they build from the teachers' own understandings; provide time for in-depth investigations, collaborative work and contemplation connecting their work clearly with the teachers' other professional development experiences and activities (Loucks-Horsley et al., 2003). Teachers can also use different types of teacher research or action research, such as constructing journals, essays, classroom studies, and oral inquiry processes; to learn from their own performances (Cochran-Smith & Lytle, 1993; NRC, 2000a)

Professional development programs that model inquiry help teachers see its importance and understand how to implement it in their own classrooms (Bentley & Alouf, 2003; DeBoer, 1991; Wallace & Kang, 2004; Windschitl, 2003). If students are to develop creativity, skillful problem solving, and critical thinking, their teachers must also possess these qualities and skills. If students are to collaborate productively, their teachers must have this capability too (Fraser-Abder, 2002).

Professional development models need to show teachers how to relate information (Supovitz & Turner, 2000; Windschitl, 2004). Content knowledge alone is useless if the teacher can not disseminate it to the students (Benford & Lawson, 2001; Loucks-Horsley et al., 2003). Using inquiry in both classroom teaching and professional development programs increases student understanding and teacher instructional effectiveness (Johnson, Kahle, & Fargo, 2007; Supovitz & Turner, 2000). Inquiry-based professional development programs can lastingly change teachers' practical knowledge and their ability to disseminate it to students (VanDriel et al., 2001).

Affects of Good Questioning Skills among Teachers and Students

While inquiry has been identified as an exceptional way to learn, few studies have focused on different types of inquiry (Benford & Lawson, 2001; NRC, 2000b; Perry, 2004). Since authentic inquiry most closely reproduces scientific study it should yield higher levels of questioning among students and teachers alike (building from simple questions requiring yes or no answers to fact-finding questions and finally to open-ended questions) (Dori & Herscovitz, 1999; Harper, Etkina, & Lin, 2003; Newmann & Wehlage, 1993).

Inquiry creates an environment where students and teachers are able to ask and answer various questions (Penick, Crow, & Bonnstetter, 1996). In most classrooms teachers, not students, ask the questions (Roth, 1995). Students have to be encouraged to pose questions because they will not form queries spontaneously (Dillon, 1988). Questioning skills, however, are important for real-world problem solving and decision making. Zoller (1987) for example, noted the importance of question forming in chemistry. Similarly, Shepardson and Pizini (1991) identified asking questions as a component of thinking skills for learning tasks and as a key stage in problem solving (Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005).

In science education, Shodell (1995) found that students who can ask questions may increase their creativity and higher order thinking skills. More recently, Cuccio-Schirripa and Steiner (2000) stated that "questioning is one of the thinking processing skills which is structurally embedded in the thinking operation of critical thinking, creative thinking, and problem solving." (p. 210). Later Hofstein et al. (2005) added that "providing students with opportunities to engage in inquiry-type experiments in the chemistry laboratory improved their ability to ask high-level questions, to hypothesize, and to suggest questions for further experimental in-

vestigations." (p. 793).

As the National Research Council has pointed out, questioning behavior is based on curiosity about how the world works and is "intimately connected" to inquiry. Questioning skills are necessary for teachers who use inquiry. Closed questions help a teacher draw attention to a feature students fail to uncover on their own (Allsup & Baxter, 2004). Answers to open-ended questions tell teachers what the students are thinking, what they know, and what they can recognize (Allsup & Baxter). Thus, when science educators create environments that both stimulate and harness the natural curiosity of young people, authentic inquiry can improve students' questioning skills and, in turn, their ability to problem solve and think critically (Rop, 2003).

Mixed Method Research Design

Mixed method research combines qualitative and quantitative analysis and can be very powerful (Frechtling & Sharp, 1997). Qualitative data provides the story or reasoning behind quantitative data, which can briefly summarize the results. Using rich description to give the reader sense-making details, qualitative methods concretely depict detail, actively present the process, and call attention to the perspectives of those studied (Firestone, 1987; Mays & Pope, 1995; Patton, 1980).

Rationale for Qualitative and Quantitative Methods

A full understanding of the implications of inquiry-based professional development programs requires using qualitative techniques and analysis. Most orthodox qualitative researchers do not start with narrowly specified evaluation questions; instead, they formulate specific questions after completing open-ended field research (Lofland & Lofland, 1995). In our mixed methods study we triangulated interviews, surveys, observations, and profiles to find consistencies and discrepancies in the qualitative data. Then we built a quantitative analysis using a survey tool.

The qualitative and quantitative methods were combined to improve the surveys and interview questions and sharpen the evaluator's understanding of findings (Mullens & Kasprzyk, 1996). A typical design usually begins with a qualitative segment to alert the evaluator to issues that the survey of program participants must explore (the quantitative segment) (Fretchling & Sharp, 1997; Tashakkori & Teddlie, 2003). This study contains both qualitative and quantitative segments.

Program Profiles

Our experimental group, UBEST, focused on authentic inquiry where the teachers designed their own small-scaled scientific research study and professional developers assisted as facilitators and mentors. It consisted of a two-week summer course with additional follow-up sessions in the fall (Hanegan & Nelson, 2002). In the first week of the 2005 summer course, 20 secondary biology teachers studied insects at an outdoor field research laboratory in the Grand Staircase Escalante National Monument in Utah. During the second week of the summer course, the teachers worked in indoor research laboratories at the university organizing their data, analyzing their work, and determining the results of their experiments. All UBEST participants and researchers participated in a listserv that continued after the two-week course. The listserv provided the teachers access to their professional development coordinators, encouraged discussion among colleagues participating in the program, and communicated logistical information. From September 2005 through July 2006, 282 messages were posted.

The matched control group, GenEd, focused on simulated inquiry in another two- week 2005 summer professional development course where the professional developers assisted as lecturers and monitors. Twenty high school biology teachers were given pre-made inquiry-based activities including computer simulations to follow. The GenEd teacher participants were contained in a university lecture/computer room setting. During the summer course, the teachers visited on-campus research laboratories and attended expert science lectures involving cancer research, basic genetic information, and computer-based technology. GenEd follow-up sessions included two Saturday workshops and monthly after-school meetings in a classroom throughout the school year at one centrally located public school campus.

Teacher Research Participants

Each professional developer chose five teachers as research participants to compare the two professional development programs based on the teachers own definitions of inquiry and responses to its implementation. Additionally, these ten teacher participants were chosen after their first classroom observation because classroom observations determined they had a high level of program outcome implementation. Teachers confirmed that they were not attending any other professional development with a focus on science inquiry, other than UBEST or GenEd, during this study. For research purposes the teachers were given aliases. The

Table 1
Data Collection and Data Analysis Sequence

Data Collected	Data Analysis
1. Baseline questionnaire (2000 National Survey of Science and Mathematics Education)	1. Participant Profile Developed
2. Baseline interview	2. Nvivo 2 software (analysis of interview tran scripts) and Analysis of Variance (ANOVA)
3. Classroom observation protocol (COP, analysis of real time classroom observations)	3. Participant Profile Confirmation
4. Two classroom observations during the fall semester	4. Noldus Observer XT software (analysis of videoed observations) and ANOVA
5. Two face-to-face interviews during the fall semester	5. Nvivo 2 software (analysis of interview tran scripts) and ANOVA
6. Final survey	6. Survey Monkey (analysis of final survey); descriptive statistics

five UBEST teachers were called Ron, Julie, Dave, Frank, and Michael. The five biology teachers from the GenEd Program were called Sherri, Matt, Lance, Heather, and Anne. Please find research teacher participant profiles in Appendix A, including years of teaching experience, personal education, grade level and subject taught during study.

Data Collection and Analysis

Triangulation gathers data from different sources and checks the findings against each other (Lincoln & Guba, 1985). This study collected data from repeated, structured, and open-ended interview questions, from survey questions and from video observations. The survey questions and the interviews supported each other.

Data collection activities began June 2005 for UBEST and July 2005 for GenEd and were completed by June 2006. Our data set included 20 videotaped classroom observations, 10 baseline questionnaires, 10 baseline interviews, 20 follow-up interviews and 10 survey responses. Data were collected and analyzed (See Table 1).

Horizon Research, Inc. developed the 2000 National Survey of Science and Mathematics Education, which was used as the baseline questionnaire for this study (Weiss, Banilower, McMahon, & Smith, 2001). The instrument provided data regarding teacher opinions, teacher background, class sizes, perceived teacher techniques, professional development courses attended, teachers' familiarity with the standards, and their perceived implementation of inquiry. After the teachers completed the baseline questionnaire, we conducted and analyzed a short baseline interview. This interview contained one open-ended question: "How do you implement inquiry into your classroom?" This question was formulated to discover the teachers' understanding of inquiry. It was used later in both follow-up interviews. The researchers did not provide the teachers with a definition of inquiry at any time during this study.

Teachers were re-interviewed and observed twice during the fall of each school year. During each subsequent interview the initial open-ended question was asked as well as several other structured questions. Horizon's (2000) classroom observation protocol was used to gain quantitative data from real time observation in the classroom and again to analyze video of the observations. Data gathered included the number of engaged students, how many open-ended and close-ended questions were asked, and the types of cognitive activities used during the lessons. After we analyzed the observations and interviews we designed and administered an online survey to triangulate the data.

Data Analysis

We used four main software tools to analyze our data: 1) Nvivo 2 (analysis of interview transcripts), 2) Noldus Observer XT (analysis of videoed observations), 3) Survey Monkey (analysis of final survey) and 4) SPSS: Analysis of Variance (ANOVA).

The software tool NVivo 2 is designed for qualitative researchers and is reasonable for working with complex data like interview transcripts (QSR International, 2005). During the summer we conducted a baseline interview with all teachers participating in the professional development programs individually prior to participation in this study. In October we interviewed

Table 2
Percentage of Class Time Teachers Devoted to Cognitive Activities by Program

Activities	Receipt of Knowledge				Application of Processed Knowledge				Knowledge Representation	
	First Observation		Second Observation		First Observation		Second Observation		First Observation	
Group	M	SD	M	SD	M	SD	M	SD	M	SD
UBEST	15.2	8.5	25.2	16.9	31.4	21.8	27.4	13.2	43.6	24.3
GenEd	38.8	23.2	31.6	37.1	53.8	18.8	54.0	29.9	6.2	6.8

	Knowledge Representation		Knowledge Construction				Other			
	Second Observation		First Observation		Second Observation		First Observation		Second Observation	
Group	M	SD	M	SD	M	SD	M	SD	M	SD
UBEST	29.6	21.2	0.0	0.0	12.8	28.6	9.8	21.9	5.4	8.3
GenEd	10.4	23.2	0.0	0.0	0.0	0.0	1.4	3.1	4.0	3.9

the 10 study teacher participants again and asked them the same initial question as had been used in the baseline interview with seven other open-ended questions added. In late December and early January we interviewed the study participant teachers a third time and asked the same eight questions as in the second interview. All interviews were recorded, transcribed and coded, and a project report was completed using NVivo2.

A video recording of each classroom observation aided the qualitative analysis. The Noldus Observer XT software allowed us to analyze length of lecture time, participation of students, and student activity and to observe the teacher's intended implementation and expectations as well as application of inquiry in the classroom. With Noldus Observer XT we also annotated such behavior as physiological measurements, questioning events, or automatically logged events (Bischof, Stark, Blumenstein, Wagner, Brechmann, & Scheich, 2001; Soria, et al., 2002). During the analysis, codes were implemented and themes were examined. Following these interviews and observations, a survey was conducted using Survey Monkey Instruments and all data were analyzed using ANOVA (Bentley & Alouf, 2003).

Findings

Coding and sorting transcriptions from interviews, observations, and survey data yielded data that showed two major differences between the programs: Differences in 1) cognitive activities and 2) questioning levels of both students and teachers.

Difference in Cognitive Activities

COP was used to observe student activities in the classroom and three researchers watched the same observation simultaneously and used Noldus video software to record the differences in cognitive activities. The interviews also showed evidence about cognitive activity; that will be discussed later. Throughout the data collection process COP enabled the researchers to identify five main categories of classroom cognitive activities:

1) Receipt of Knowledge (RK): Students were involved in the rote reception of information, including listening to a lecture, going over homework, or watching a teacher verify a concept through demonstration. The key feature of this category is that students receive information but do not significantly do anything with the information.

2) Application of Procedural Knowledge (APK): Students applied their knowledge, typically by doing worksheets, practicing problems, or building skills. The key feature of this category is that students take information and apply or practice it.

3) Knowledge Representation (KR): Students manipulate information, usually by taking what they have learned and reorganizing, categorizing, or attempting to represent it in a different way. For example, students might take dab data and graphically represent them. Usually just beyond application, this category features the reorganization or representation of information.

4) Knowledge Construction (KC): Students generate

new meaning by creating new understanding or making new connections. Students might be producing ideas or solving new problems. For example, they might generate patterns that hold true for three different labs. The key feature of this category is that students generate new knowledge or meaning.

5) Other (O): This category includes activities not included above, such as classroom disruptions or classroom organization such as changing seat assignments.

Table 2 summarizes the cognitive activities found in the two programs. UBEST participants invested most of their observation time in knowledge representation whereas GenEd participants spent most of their time in the application of procedural knowledge. A repeated measures test was conducted using ANOVA because each teacher was observed twice and one observation of each teacher was dependent on the other. A t-test, therefore, could not be conducted; a repeated measures test was the proper choice. The knowledge representation category was found to be statistically significant, $F = 7.67$, $p < 0.0243$. UBEST participants spent more time in the knowledge representation category than did the GenEd participants.

Qualitative analysis developed a deeper understanding of the differences in time spent in cognitive activities as shown in the following selected teacher excerpts. While being interviewed, the teachers were not aware of their students' cognitive activity level.

Receipt of Knowledge:

> GenEd: They had to read a book related to biology and then do a critique of the book, and they chose books that were meaningful to them as well, and so – there's inquiry in that in the sense that they're interested in - they're wondering what the book is going to tell them, but it's sort of removed a little bit. (Sherri)

Application of Procedural Knowledge:

> GenEd: I put some cornstarch in a baggie and I put an iodine solution in a beaker and I had them make some observations about the color of the cornstarch solution and the color of the iodine solution before we started and I put it in the solution and then I taught them about the different types of transportation. (Heather)

> UBEST: I've tried to kind of scaffold the structure so that they get more and more, or rather less and less cookbook as we go. So, we started out with labs that were very prescribed, "and do this and do this and do this…", and then each successive lab gets less and less "do this, do this, do this" I try to leave them a little more open ended. (Julie)

Knowledge Representation:

> GenEd: We have a decomposition pit over here, the students built the pit - they put it together. This is one of the things that the boys really liked and some of the girls. They were using saws, bolts, nuts, nails and chicken wire. We have in the pit some cow hearts and fetal pigs. Some of the material has been treated for dissection, so it's got preservative in it. The students are writing compare and contrast essays using different rates of decomposition. (Lance)

> UBEST: So what I've been trying to do is present the information and then see what conclusions they come up with and then correct their errors of thinking, but letting them try and put the pieces together. They hate it when I just give them the pieces and I don't give them the answers. (Ron)

Knowledge Construction:

> UBEST: At the end of the lesson, I wanted them to mix any two things that hadn't already been mixed. They could choose and make predictions based on what they had already seen. (Michael)

> UBEST: I give them a general objective. They can do it any way they want as long as it's safe and I have the equipment to do it. They're going to come up with a lot of questions. They're going to find out that they've made a lot of mistakes, compared to what the data shows. And then we're going to discuss "how could you refine this?" Some of the ideas these kids are coming up with I've never thought of before. (Dave)

The interviews covered classroom cognitive activities as well as the reasons why the teachers chose those activities. During the interviews, the prompt question was: "Could you show me an assignment/task that you've used in the past couple of weeks that includes what you learned in UBEST [GenEd] this summer?" The UBEST participants more often described Knowledge Construction or Knowledge Representation lessons and this preference was observed in their classrooms and GenEd participants more often de-

Table 3
Mean Number of Open-Ended Questions Asked per Minute by Group

Group	Teacher-Initiated Open-Ended Questioning				Student-Initiated Open-Ended Questioning			
	First Observation		Second Observation		First Observation		Second Observation	
	M	SD	M	SD	M	SD	M	SD
UBEST	0.12	0.09	0.10	0.10	0.04	0.07	0.05	0.04
GenEd	0.03	0.04	0.03	0.01	0.01	0.01	0.01	

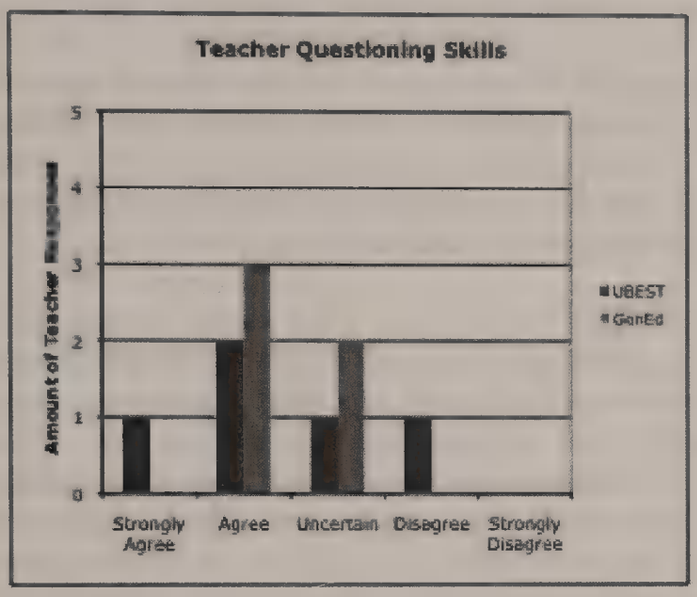

Figure 1. Teacher responses to the question: "Please indicate your agreement with the following statement: UBEST [GenEd] improved my questioning skills with students."

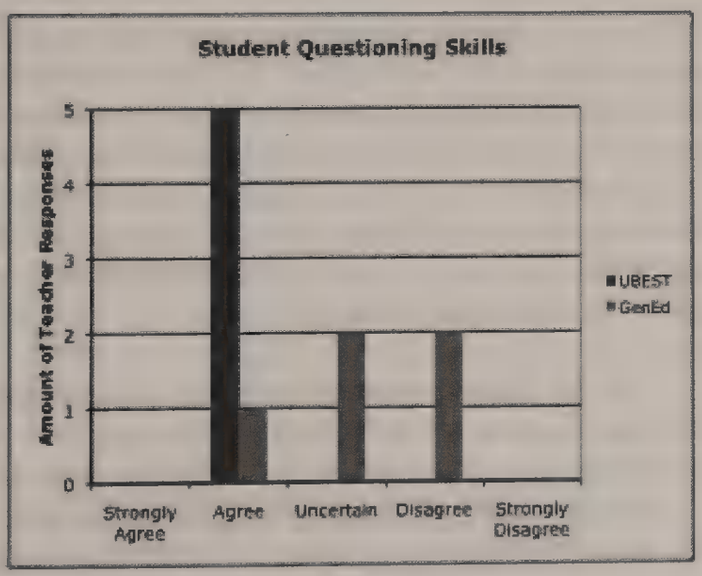

Figure 2. Teacher responses to the question: "Please indicate your agreement with the following statement: My students' question levels have increased (example: asking fewer yes/no questions and more factual or open-ended questions) over the course of this year."

scribed Application of Procedural Knowledge activities. Alignment of interviews and observations leads to the reasonable comparison of differences in cognitive activities, especially Knowledge Representation, between the two programs.

Difference in Questioning Levels of Both Students and Teachers

The COP observations indicated that engagement levels differed from classroom to classroom but no specific explanation for this difference could be found until the videotapes were viewed and sorted with Noldus. Participants in the two programs employed significantly different questioning levels and open-ended questioning between students and teachers created an immense difference among the classrooms. We defined three different questioning levels and ranked them from lowest order to highest: 1) In yes/no (objective) questions the response is always either yes or no. 2) With factual (repetition) questions teachers or students ask straightforward, and usually rote, questions that typically have a definitive answer. 3) Open-ended questions, whether posed by teachers or students, do not have a single answer. These questions promote a higher level of thought among the students.

Table 3 graphically portrays the significant questioning differences between participants in the two programs. Dave, Frank, and Julie (UBEST teachers) asked many open-ended questions. Students of Michael, Ron, Frank, and Dave (also UBEST participants) asked many open-ended questions, a number that was found to be statistically significant. We ran a repeated measures ANOVA on the response; the range of reasonable values for the difference is -6.7576 to -0.4424. This interval does not include 0. So if GenEd-UBEST < 0, then GenEd < UBEST in students'open-ended questions. UBEST produced more open-ended questions from students, $F = 6.91$, $p < 0.0302$.

This increase in students' open-ended questions is found not only in the classroom observations but also in the survey administered six months after the initial summer two-week course. Two survey questions cov-

ered questioning levels in the classroom: 1) "Please indicate your agreement with the following statement: The UBEST [GenEd] improved my questioning skills with students." 2) "Please indicate your agreement with the following statement: My students' question levels have increased (example: asking fewer yes/no questions and more factual or open-ended questions) over the course of this year." Teachers were given the options of strongly agree, agree, uncertain, disagree, or strongly disagree.

Figure 1 shows no clear majority for either group. Often teachers do not recognize how many or what kind of questions they ask. However, the video observations clearly recorded the use of open-ended questions and factual questions. Figure 2 shows UBEST teachers believed that their students' levels of questions increased. Both the classroom observations and interviews recorded this increase. GenEd teachers had no majority belief about student questions.

Although teachers in both programs described the types of questions they asked students, UBEST participants talked much more about questioning. Teachers' descriptions of questioning can be divided into three categories: 1) descriptions of their own questioning skills, 2) their rationales for asking open-ended questions, and 3) their descriptions of students' questioning skills. Interviews with GenEd teachers produced no examples of the last two categories, a finding consistent with the lack of a majority response on the survey.

Category one: Teachers' descriptions of their own questioning skills. The quotations below exemplify teachers' understanding of their own questioning skills. Teachers from both programs knew that they asked questions during inquiry lessons. The following teacher responses expand upon this understanding:

> GenEd: When I'm doing notes and stuff, I just try to ask questions to make them think and connect. That's about as far as I go there. Matt

> GenEd: I gave them a question like how much weight would an earthworm hold before it snaps? And they've got to formulate the experimentation, do it and show it to me. Lance

> UBEST: When I ask them a question like describe how - pick something in any ecosystem they want or any biome they want and describe how - be specific in describing how something affects something or describe like, for example, a food chain in a tundra biome. Frank

Category two: Teachers' rationale for open-ended questioning skills. Teachers in UBEST were very aware of their purposeful use of open-ended questions. In the quotations below they describe themselves as facilitators who use questioning to negotiate the lessons learned with their students. Their descriptions and rationales indicate that they intended to use open-ended questions to help students hone their thinking skills:

> UBEST: I've tried to kind of help them come to their own answers, whether they're right or wrong. I ask, so why do you think this happened? or What did you expect to happen? Why was it different from what actually did happen? Julie

> UBEST: For me, inquiry is always usually open-ended questions, problems that are put on the board, So, what do you think? Michael

> UBEST: One of the ways is for me not to answer students' questions, for me to redirect a question back to a student. I say, Tell me what you're learning. Tell me what you're observing. I tell the students to talk among themselves and teach each other the things they're learning. I really try to avoid asking them questions. I ask them questions if we kind of get stuck, and sometimes we need them. Dave

Category three: Teachers' descriptions of student questioning skills. During their interviews UBEST teachers described the types of questions their students were asking as a result of authentic inquiry. They spoke of the moments that students asked spontaneous questions as a result of realization, as well as curiosity. They also described how the students' questions lead to a deeper understanding:

> UBEST: The ultimate question is the best question that is answerable. It's relevant to this class and it's challenging. We gave them three things and fifteen minutes to look through their lab books and journals and in teams they came up with the ultimate question. And Adam came up with; How come killing slugs with salt is a good example of osmosis? Dave

> UBEST: The students are actually coming to me now and saying, Why do the dragonflies have blue

and green on their eyes and stripes? And I said, you know, I don't know. Maybe you better find that out. Or, how fast do you think these wings are beating? How strong do you think the jaws are on a dragonfly or on a beetle, tiger beetle? And I say, Do you think you could find that out? Frank

UBEST: How did you decide if it was elliptical, spiral, or irregular? How did you decide and where did you cut off? Cause that's when they (the students) all went, "do I have to do all these little dots, too?" And that's when I said, You tell me in your procedure where you stop counting them. Michael

UBEST: It's more successful because they (the students) have so many questions. And that leads to other things. Ron

In the interviews teachers who themselves asked more open-ended questions and those who had students who asked more open-ended questions more often brought up the subject of questioning skills. These discussed both student questions and teacher questions. Also, UBEST participants focused more on student-directed questions (the student drives the flow of the lesson) than on curriculum-directed questions (the planned curriculum directs the flow of the lesson).

Class discussions are a key component in inquiry teaching. The use of discussion in the classroom emerged as a topic during the interviews and both groups reported a high percentage of discussion in their classrooms. Both groups reported increased discussion skills (which include questioning back and forth between student and teacher). The UBEST group (7.7 %) had slightly higher percentages than the GenEd group (5.2%), although the difference was not statistically significant in a repeated measures ANOVA test ($F = 0.97$, $p = .3544$ for questioning skills; $F = 0.48$, $p = .5094$ for discussion). In the interviews only Dave discussed questioning skills in depth.

To implement inquiry and promote student questioning skills the teacher can also assume the role of facilitator. For example, the students may work in groups while the teacher consistently interacts with them. The students usually work on a project or lab experiment and the teacher manages interactions so they stay focused, ask more questions, and continue to make progress. "The context provided by open-inquiry experiments offers teachers many opportunities to interact with students in the non-exclusive roles of coach, facilitator or guide in learning." (Roth, 1995, p. 247). Interactions between facilitator-teachers and students were noted in the observations and percentages were computed. Both programs had good student interaction times. On average, UBEST participants interacted 46.8% of the time with their students and GenEd participants interacted with their students 40.3% of the time.

Summary and Discussion

Initially this study was designed to probe the differences in teacher implementation of authentic or simulated inquiry by examining which type of inquiry created higher level cognitive activities and questioning skills for teachers and students. Two main differences between the inquiry methods were found to be statistically significant: 1) cognitive activities and 2) questioning levels in both students and teachers.

While participants in both programs produced increased levels of teacher-to-student interaction, discussions, and student cognitive activities in the classroom, UBEST participants showed a higher level of these activities. Four of the five UBEST teachers devoted more than 50% of their teaching activities to knowledge representation or knowledge construction, while all five of the GenEd participants spent more than 50% of their time in receipt of knowledge or application of procedural knowledge. UBEST teachers asked more open-ended questions in their classrooms and, in return, their students formed more open-ended questions. Students' open-ended questioning was statistically significant between the two programs. This seems directly related to the active engagement in authentic inquiry of the UBEST teachers; an engagement that must have affected the classroom.

When performing authentic tasks the teacher becomes classroom-driven rather than curriculum-driven. In classroom-driven teaching (promoted by authentic inquiry), student's questions and attitudes are the basis for classroom activities. Students' responses and questions give the teacher classroom direction. The teacher may begin the class with a topic and activity in mind but student questions about the activity will drive the teacher to create new tasks. In contrast, curriculum-driven teaching (promoted by simulated inquiry) forces the teacher to allow the planned curriculum to drive the classroom. The curriculum, not the students, is the teacher's guide. If a professional development program models authentic inquiry the teacher will be lead to understand the students' role and, thus, to focus on,

and anticipate, student interaction and questioning.

If teachers become classroom facilitators they can guide students to uncover their own learning. To perform the diverse and complex roles of the teacher-facilitator, teachers need their own science learning experiences that incorporate scientific inquiry. Teacher and student learning are inextricably linked (Darling-Hammond & McLaughlin,1995; Fullan, 1996; Hofstein et al., 2005; Jeanpiere, Oberhaurser, & Freeman, 2005).

Nelson and Hanegan (2003) found that teachers who had experienced intensive field science professional development overwhelmingly reported improved science content knowledge. With improved science content knowledge teachers become more confident of their teaching abilities and that confidence allows them to embrace student-centered learning. By deepening content knowledge, authentic inquiry can allow for more classroom-driven instruction.

When teachers use authentic inquiry in the classroom, good questioning should follow. Decades ago Sloan and Pate (1996) found that compared to traditional mathematics teachers, the "new math" teachers; who were in a program that emphasized inquiry and discovery, asked significantly fewer recall questions and significantly more comprehension and analysis questions (Gall, 1970). In this study a higher level of questioning was found in the UBEST program, which employed authentic inquiry.

When students take control of their learning they ask more in-depth and open-ended questions. These questions can lead to increased knowledge, understanding of science processes, and reasoning skills. Lawson and Worsnop (1992) found high school biology students' reasoning ability was significantly related to gains in conceptual knowledge. Our study indicates that authentic inquiry stimulates classroom-driven instruction and simulated inquiry promotes curriculum-driven instruction.

Implications for Future Research

The next obvious step to this study is to scale up the analysis, as well as scale up professional development programs to assist teachers with implementation of authentic inquiry. The authors suggest scaling authentic inquiry will require grant funding to support large-scale collaborations consisting of multiple university lead research groups (Kelly, 2000; Weiss & Pasley, 2006). These collaborations should include teams of STEM faculty working along side education faculty, as well as informal science education groups to provide teachers with the necessary resources and knowledge to conduct their own self-designed authentic inquiry experiences. Multiple collaborations with consistent goals and outcomes with teams of evaluators will provide a large data set to strengthen quantitative analysis.

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Appendix

Program	Teacher	Years of Teaching Experience	Education (degree)	Grade Level	Subjects	Grade Levels, Subjects Observed	Amount of Professional Development in the Last 3 Years
UBEST	Frank	7	Bachelor's: Biology/Life Science	9th	Earth Systems	9th grade Earth Systems	16-35 hours
UBEST	Ron	4	Masters: Curriculum and Teaching Bachelor's: Biology, minor in Chemistry	7th; 9th	Integrated Science; Earth Systems	7th grade Integrated Science	16-35 hours
UBEST	Michael	1	Masters: Teaching and Learning Bachelor's Biology/ Life Science	7th; 8th	Integrated Science; Pre-algebra	8th grade Integrated Science	none
UBEST	Julie	2	Bachelor's: Biology/ Life Science, Chemistry	7th; 12th	Integrated Science; Integrated Science II; Physics; Earth Systems; Biology	Earth Systems; 7th grade Integrated Science	6-15 hours
UBEST	Dave	17	Masters: Earth/Space Science, Geology Bahcelor's: Earth/Space Science, Physics, Geology	9th-12th	Physics; Geology; Earth Systems; AP Environmental Science	AP Environmental Science	More than 35 hours
GenEd	Lance	18	Masters: Biology/Life Science Bachelor's: Marine Biology	10th; 12th	Biology; Ornamental Horticulture; Marine Biology; Advanced Biology	Biology	More than 35 hours

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Program	Teacher	Years of Teaching Experience	Education (degree)	Grade Level	Subjects	Grade Levels, Subjects Observed	Amount of Professional Development in the Last 3 Years
UBEST	Frank	7	Bachelor's: Biology/Life Science	9th	Earth Systems	9th grade Earth Systems	16-35 hours
UBEST	Ron	4	Masters: Curriculum and Teaching Bachelor's: Biology, minor in Chemistry	7th; 9th	Integrated Science; Earth Systems	7th grade Integrated Science	16-35 hours
UBEST	Michael	1	Masters: Teaching and Learning Bachelor's Biology/ Life Science	7th; 8th	Integrated Science; Pre-algebra	8th grade Integrated Science	none
UBEST	Julie	2	Bachelor's: Biology/ Life Science, Chemistry	7th; 12th	Integrated Science; Integrated Science II; Physics; Earth Systems; Biology	Earth Systems; 7th grade Integrated Science	6-15 hours
UBEST	Dave	17	Masters: Earth/Space Science, Geology Bahcelor's: Earth/Space Science, Physics, Geology	9th-12th	Physics; Geology; Earth Systems; AP Environmental Science	AP Environmental Science	More than 35 hours
GenEd	Lance	18	Masters: Biology/Life Science Bachelor's: Marine Biology	10th; 12th	Biology; Ornamental Horticulture; Marine Biology; Advanced Biology	Biology	More than 35 hours

Development of a Community of Science Teachers: Participation in a Collaborative Action Research Project

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This article presents a study exploring the beliefs, knowledge, and practices of four middle and secondary science teachers participating in a collaborative curriculum action research project. Using a case study methodology, the views and practices of these teachers were described and analyzed as they investigated novel ideas about scientific inquiry and nature of science, critically examined their practice, and implemented and reflected upon modified curricular practices. Findings indicated that by the end of the study, all participants had enhanced their views of scientific inquiry and nature of science, and the collaborative group evolved as a community of teachers. Wenger's (1998a) community of practice theory provided a useful framework to describe and analyze the experiences of these science teachers. Implications for the professional development of science teachers and the compatibility between a community of practice and collaborative action research projects are presented.

When science standards or learning outcomes are established, educators must consider the design of effective instructional and assessment strategies to support student learning of these outcomes. Some argue that the power of these standards (e.g., National Research Council, 1996) lies in their capacity to stimulate reform in the educational system (Bybee & Loucks-Horsley, 2001). Yet to stimulate any reform effort, teachers must be at the focal point. Furthermore, teachers require the requisite beliefs, knowledge, and skills to facilitate the type of learning required to realize science education reform efforts. Accordingly, professional development is critical with any standard-based reform initiative and to support these reform efforts "…teachers will have to unlearn much of what they believe, know, and know how to do while also forming new beliefs, developing new knowledge, and mastering new skills" (Thompson & Zueli, 1999, p. 341).

The curriculum emphasis of scientific inquiry (SI) goals and, to a lesser extent, nature of science (NOS) within current science curricular reform documents (American Association for the Advancement of Science, 1993; Council of Ministers of Education, Canada, 1997; Ministry of Education and Training, 1999; National Research Council [NRC], 1996) underscores the importance of teaching SI and NOS in science education. According to Lederman (2006), situating NOS within the context of SI can support current reform efforts; however, he goes on to say that "…there is much confusion about the distinction between nature of science and scientific inquiry. The two are intimately related and there is critical overlap" (p. 308).

SI refers to the systematic approaches used by scientists to address scientific questions about the natural world (Lederman, 2006). Students engaged with inquiry-based curricula may be primarily learning scientific concepts and principles, while engaging in science-specific process skills (e.g., observing, measuring, analyzing), or may be carrying out an open inquiry, whereby they are designing and conducting an investigation on their own. NOS, in contrast, is a fertile hybrid of science, which includes its history, sociology, and philosophy, producing a rich description of what science is and how it works (McComas, Clough, & Almazroa, 2000). For educational contexts, NOS can be succinctly described as the epistemology of scientific knowledge, and how this knowledge is influenced by scientists within the social and historical context of their practice (Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001).

Regardless of the perennial call for addressing the teaching and learning of SI and NOS, evidence suggests that these goals are not reflective of normal classroom practices of science teachers or outcomes of student learning (Bybee, 2000; Lederman, 1992, 2006, 2007; Nadeau & Desautels, 1984). Teachers should possess beliefs and knowledge that are congruent with these reform goals if they are to translate their understanding into appropriate curricular experiences for students, thus, effective teacher development opportunities are necessary to address these professional beliefs and knowledge.

With respect to professional development, a large

scale study of science and mathematics teachers (Garet et al., 2001) revealed the following conditions for effective professional development: sustained and intensive, focused on academic subject matter, opportunities for active learning, integrated into the context of the school, and occurs within a collaborative group. Together, these professional development conditions are more likely to produce enhanced teachers' beliefs and knowledge. Furthermore, collaborative action research is well-suited to attend to these conditions for effective professional development and begins to attend to the relatively new domain of developing and researching science teacher learning communities.

In this study, findings are presented based on the participation of four science teachers and a facilitator (author) in a collaborative action research project. The following research questions provided foci for this exploratory study:

To what extent will the teachers' beliefs and knowledge about SI and NOS change from their participation in this project?

How will the collaborative group develop throughout the action research project?

Theoretical Perspectives

Teachers' Beliefs and Knowledge about SI and NOS

Practicing teachers develop their beliefs and knowledge from many years spent in the classroom as both students and teachers (Nespor, 1987; Pajares, 1992). Teachers' beliefs and knowledge are interrelated, yet, distinct philosophical cognitive constructs. Both constructs have implications for teacher practice. The term *views* will be used in this article to describe an amalgamation of beliefs and knowledge. Other educational researchers (e.g., Crawford, 2004) have also used these concepts (views, beliefs, knowledge) in this manner for data analysis and interpretation.

Unfortunately, many teachers have not had an opportunity during their secondary and post-secondary science experiences to learn the academic content knowledge necessary to equip them to teach SI and NOS effectively (Lederman, 2006, 2007; Windschitl, 2004). Furthermore, faculties of education inconsistently prepare teacher candidates with the appropriate pedagogical content knowledge to teach these concepts (Lederman et al., 2001). Consequently, it is not surprising that the beliefs and knowledge of teachers are not necessarily consistent with curricular reform efforts (Lumpe, Haney, & Czerniak, 2000). Since teachers' beliefs and knowledge can guide their instructional practices and curricular decisions (Fang, 1996), fruitful research involves exploration and elucidation on how to enhance teachers' views in order to realize recently proposed reforms.

Teacher Development, Collaborative Action Research, and Community of Practice

Effective teacher development is long term, school-based, collaborative, and focused on student learning (Darling-Hammond & Sykes, 1999; Hewson, 2007). Indeed, one-off professional development using seminars or one-day workshops do little to enact new learning that is required for teachers to implement science education reforms (Johnson, 2006; Klentschy, 2005). Other researchers have conjectured that teaching and learning are strengthened when teachers collectively question their own teaching practices, examine new conceptions of teaching and learning, generate ideas to collectively problem-solve, and engage actively in supporting one another's personal and professional growth (Grossman, Wineburg, & Woolworth, 2001; Little, 2002; Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003). In essence, these researchers are describing collaborative-types of action research experiences.

Action research is an ongoing process of systemic study in which teachers examine their own practice and take action to improve teaching and learning within their own classroom situation. More specifically, it involves cycles of problem formulation, planning, action, reflection, evaluation, and communication (Carr & Kemmis, 1986; Elliott, 1991; McKernan, 1996). Action research has been utilized in three domains of science education: teacher education; classroom teaching and learning; curriculum development and implementation (Feldman & Capobianco, 2000).

Teachers are under tremendous pressure during curriculum reform periods to implement new instructional practices. Collaborative action research may help to meet reform goals, yet, it is idealistic to assume that teachers are able to individually initiate collaborative-types of action research projects. What are required to support these projects are facilitators who assist in the action research process while systematically studying the project participants (McKernan, 1996). Other action research projects (Fazio, 2005; Goodnough & Cashion, 2006; Hodson, Bencze, Elshof, Pedretti, & Nyhof-Young, 2001) have had success using a collaborative model with a facilitator. This current project was similarly aligned with these other collaborative action research projects.

Collaborative action research, conceptualized as a

community of practice (CoP) (Wenger, 1998a) is well-suited to attend to condition for successful professional development. CoP theory originated in J. Lave and E. Wenger's social-cognitive research (Lave & Wenger, 1991), where they described and analyzed empirical evidence from learning apprenticeship cases. Based on their interpretations they formulated a comprehensive theory of learning as social practice:

> In our view, learning is not merely situated in practice – as if it were some independently reifiable process that just happened to be located somewhere; learning is an integral part of generative social practice in the lived-in world (p. 35).

They envisaged that their theoretical approach would be relevant to all areas of social practice, including education. A CoP can be defined as the basic component of a social learning system that is formed by individuals who participate in a process of collective learning within a shared domain. According to Wenger, McDermott, and Snyder (2002), communities of practice have the following characteristics:

Domain: A CoP is not merely a group or network of individuals; it has an identity defined by a shared domain of interest. Membership implies a commitment to the domain, and a shared competence that distinguishes members from other non-members.

Community: In pursuing their shared domain of interest, members participate in joint activities and discussions, assist each other, and share information. They build collaborative relationships that allow learning to occur.

Practice: Members of a CoP are practitioners who develop a shared repertoire of resources: experiences, stories, tools, artefacts, and methods for problem-solving, that is, members have a shared practice.

It is the interrelated combination of these three elements that cultivates a learning community. Since knowledge production in a communal context consists of participants' shared experiences and new understandings developed within a group (Putnam & Borko, 2000), the act of participation within a community of practice is critical for enhancing teachers' views of SI and NOS. Little (2003) has stated that "…relatively little research examines the specific interactions and dynamics by which professional community constitutes a resource for teacher learning and innovations in teaching practice." (p. 913). This research contributes to this relatively unexplored area of science teacher development and professional learning communities.

Context of the Study

The Collaborative Action Research Project

This project involved four science teachers and a facilitator (the author) participating for the duration of the 2003-2004 academic school year. The collaborative group was established from volunteers from a science education Master's level graduate program who were interested in undertaking action research in their science classrooms. While there are many orientations to action research, there was no attempt to categorize the type of action research projects the teachers were to carry out. According to Elliott (1991), the initial phase of action research involves identifying and clarifying the research idea, a reconnaissance of the literature, and construction of a general plan of action. All the teachers participated in these stages. At the end of the first meeting it became clear that the participants were embarking on highly individualized action research projects, as opposed to a common group action research project. Nonetheless, they all agreed to implement a project unified under the placard of two science curriculum reform ideas (i.e., SI and NOS).

At the beginning of the project, the author clarified to the participants that he would be both a researcher and a facilitator of the teachers' participation in the project. In these roles, the facilitator provided action research resources and references and referred to them frequently during the initial collaborative meetings; set the context for initial meeting; offered support as the action research projects were being implemented; established group rapport and fostered group collaboration; discussed salient knowledge concerning SI and NOS.

The science teachers in this project explored ideas and theories related to the teaching and learning of SI and NOS, critically examined their practice, designed or modified curricular materials and refined their practices based on their individual action research project. These projects aligned with key components of current SI and NOS curriculum reform ideas. Their professional backgrounds and projects are briefly detailed below.

Participants

All participants were from different school districts and did not know each other or the facilitator at the onset of the project. The recruitment of the volunteers, through purposive sampling, was seen as preferable to a probabilistic or random sampling strategy because it supported the scope and range of data collected for a

naturalistic and qualitative study (Lincoln & Guba, 1985). The following accounts briefly describe the participants' and their individual action research projects. Pseudonyms are used throughout this article.

Luke was in his fourth year of teaching during this project. He had experience teaching Grade 9 and 10 general sciences along with Grades 11 and 12 senior chemistry and International Baccalaureate (IB) chemistry at a suburban secondary high school. Luke's action research project was titled: "Improving students' communication skills when reporting on scientific investigations."

Alicia had just entered her fourteenth year as a teacher when she participated in the collaborative project. She teaches at an urban secondary school and has taught Grade 11 and 12 biology, 9 and 10 general sciences, and Grade 11 chemistry. Alicia's many years of teaching experience has given her an opportunity to teach all secondary science courses, in addition to non-science subjects such as mathematics and drama. Alicia's action research project was titled: "Promoting student-centred and problem-based learning using scientific investigations."

James was entering his twelfth year of teaching when the project began. He had taught a unique senior science course called, "Science in Society" and over his teaching career had taught a variety of science classes, including Grades 9 and 10 general sciences and senior level biology, chemistry and physics. He currently teaches at a secondary school in a suburban community. James' action research project was titled: "Facilitating student learning of the theory-laden and tentative aspects of science, using historical and philosophical perspectives."

George was a relatively new teacher, entering his second year of teaching in an urban elementary/middle school (Kindergarten to Grade 8). His subject teaching experiences are broad considering his official 'novice' status. He has taught Grades 6, 7, and 8 science and technology courses, and has also taught Grade 7 history, geography, and the arts, although he indicated that he would prefer to teach in a secondary school. George's action research project was titled: "Supporting and assessing students' scientific inquiry skills during the development of science fair projects."

Research Methodology

A collective case study methodology (Stake, 2000) was used to describe and interpret the ideas and actions of each teacher. Although teachers collected data from their classroom, the research reported here is of the four teachers' experiences and espoused views situated outside their classroom practice. The aim of this approach was to provide detailed descriptions and analyses of each teacher's expressed views, experiences over the course of their participation within the collaborative action research project, and document changes that may be attributable to their participation. Various observational and narrative methods were used to capture teachers' oral and written discourses throughout the research period (Connelly & Clandinin, 1986; Erickson, 1998; McKernan, 1996; Miles & Huberman, 1994).

Interviews: Each teacher was interviewed using semi-structured interview protocols prior and subsequent to the collaborative action research project. The purpose of the interviews was to provide data concerning their views of the teachers participating in this collaborative action research project and to assess any changes in their views of SI and NOS. The interview protocol was adapted from the *Views of Nature of Science* (VNOS) questionnaire developed by Lederman, Abd-El-Khalick, Bell, and Schwartz (2002). Questions regarding SI were also added to this protocol. In addition, a final interview was administered at the conclusion of the project to elucidate their overall experiences as participants in this project. All interviews were audio recorded and later transcribed.

Collaborative meetings: Twelve collaborative action research meetings took place throughout the project at the local university. Each meeting was approximately two hours in duration. The intent of the meetings was to share ideas, critically examine and reflect upon teachers' views and current practices implementing their action research projects, and collaboratively reflect on the processes and products stemming from the action research projects. All dialogue from these meetings was audio recorded and later transcribed for analysis.

Journals: Each participant (including the researcher/facilitator) maintained a personal journal to document ideas and monitor her/his learning during the life of the project. The journal entries of the participants provided an archive of their learning throughout this project.

Codes can be generated using two main approaches: a priori and grounded. A priori codes are generated from the conceptual research framework (Freeman, 1998). In contrast, grounded codes are generated from the data themselves and are described using in vivo descriptors a constant-comparative method (Glaser,

1992). Interviews, journals, and collaborative meeting transcripts were coded using both approaches and data displays were also used to enhance the analytical process (Miles & Huberman, 1994). First-level coding (e.g., labels, tags, and categories) was used to label a unit of data that was potentially meaningful. This method was used to compare incident to incident (e.g., collaborative meetings), and then incident to concept (e.g., meeting reflections and CoP descriptors). This approach to data analysis is considered a refinement of 'classic' grounded theory (see Charmaz, 2000). It is an inductive-deductive methodological cycling between data, theory, and data again, and goes beyond a constant-comparative method by the application of theory (in this case CoP theory) to the data in reiterative cycles.

For a priori coding, data from the interviews were initially analyzed using codes generated from a list of descriptors addressing SI and NOS qualities found in the current science education literature. These descriptors became sources for codes and served as criteria to evaluate teachers' views of SI and NOS. Coded data were clustered and then categorized to identify themes and patterns that describe and interpret the ideas and actions of the teachers in the collaborative group. To enhance the validity of the data analyses, triangulation was accomplished vis-à-vis multiple sources of data (e.g., interviews, meetings, and journals). Furthermore, prolonged involvement of participants in the study and the use of member checks ensured achievement of a reputable level of data trustworthiness (Lincoln & Guba, 1985).

Findings

Analyses of the data revealed findings which are categorized under the following headings: changes in teachers' views, domain of SI and NOS, community of science teachers, and collaborative practice. Illustrative quotes and text excerpts from the participating science teachers are presented as a description of the changes in individual teachers' SI and NOS views and group development in this collaborative group project.

Changes in Teachers' Views

The interview data suggested that the teachers' views changed as they engaged in the construction, evaluation, and acceptance of knowledge while concurrently dealing with the emotive components of belief reconstruction. For instance with Luke, implementing his action research project offered him reflective opportunities which allowed him to augment his personal views about SI and NOS:

> I know I wasn't too experienced with NOS or SI and I didn't give it critical thought. This [action] research project allowed me to develop my own thoughts and pass it on to my teaching, and in turn to my students....I think I'm more aware of scientific inquiry, or just knowing more that science teaching should be about getting the students to think independently. I realize I got to this point through self-investigation. I think it's very important to highlight that point. (Luke, post-project interview response)

The opportunity to reflect increased his self-efficacy as a teacher and, in turn, changed his views as a science teacher; that is, these experiences enhanced his personal development of SI and NOS. In his final journal entry, Luke explicitly commented on how the collaborative process and his individual action research project, concomitantly, contributed to this development:

> Throughout this action [research], I found myself unintentionally clarifying the idea of scientific inquiry. This may have resulted from discussions in our group action research meetings. After each action in my class I was forced to consider successes and failures of my action and, in turn, possibly transform or maintain teaching strategies that were either successful or unsuccessful. I think the project allowed me to hear what I was conveying in thoughts and ideas in my classroom. I found the research self-assessing my teaching which allowed me to realize inefficiency in myself. I found myself being unsure of objectives of intent, and more concerned with the 'what' rather than the 'how' when delivering my lesson. (Luke, journal entry)

Luke's initial views of NOS were not well-formalized at the beginning of the project, and eliciting NOS ideas was a novel experience for him. The preliminary interview with Luke revealed inconsistent remarks with respect to contemporary views of NOS. For example, the following are his views regarding the development of scientific knowledge before the project began:

> So using knowledge that we know and expanding that knowledge to develop new forms of knowledge and discovery of the new forms of knowledge. Science is [about] understanding the world around us, the world of everything that we see, and try to find an explanation for everything that we

> see…and trying to come up with something to try to explain that. (Luke, preliminary NOS interview)

When queried again at the end of the project, some changes to Luke's views were evident. While he still held a strong belief in the role of experiments for empirical development of scientific knowledge, he did recognize that "…theories without proving it because that is what they [scientists] currently believe. An experiment can be used to prove or disprove, but you can further scientific knowledge without the use of experiments" (Luke, final NOS interview). Luke not only demonstrated an improved agreement with respect to a contemporary view of the theory-laden aspect of science, but indicated that a scientist's personal belief can influence the collection of evidence and development of explanations. As well, this augmented view manifested itself in his classroom practice:

> I think that I have changed how I emphasize things in the classroom. I make it a point to emphasize the limitations to certain theories, I always find myself saying: 'for now'…now we do discussions at the end of labs and always suggest ideas for further research which leads them to formulating their own questions and it's tough for them [the students] to do that because they have not had the experience. So I've changed in that way. (Luke, post-project interview)

Even so, Luke still struggled with certain contemporary tenets of NOS and his preliminary views were maintained with respect to the social-cultural embedded aspect of science:

> While there are a lot of examples where perspectives are related to the person's cultural, social background, certain things transcend cultures. I think interpretations may be different, but not for scientific inquiry. I can't see how this would be different, and that it's a standard universal practice. I can't see how things could be done differently at this point of my understanding. (Luke, final NOS interview)

George also described himself as possessing a better conceptual understanding of both SI and NOS due to his participation and actions:

> I definitely feel more confident because I have a better understanding of the nature of science and scientific inquiry based on the discussions we've had as a group and my own reflections in the implementation of my action research. (George, post-project interview)

The opportunity to learn about SI and NOS, both from documents and the other participants' experiences helped George to critically examine his curriculum practices. Nonetheless, as a new teacher he struggled with this critical examination:

> It was hard for me to investigate the students and their understanding of science as opposed to my delivery of SI, and I struggled with that and how well the students were getting it...My inexperience as a science teacher also contributed to this. To be introduced to the science curriculum and to also [examine] the way I delivered it at the same time was difficult. It was beneficial, but made it difficult for me because I struggled with issues related to how I should best deliver this to the students. (George, post-project interview)

By the end of the project, all of the teachers were more capable of explaining their current NOS views, and were better able to problematize the current mandated science curriculum, resources, and their own practices with respect to some of the NOS tenets. Specifically, they seemed to adopt a better understanding of the theory-laden aspect of science, felt confident in explaining the tentative nature of science, and reaffirmed that a significant component of scientific practice involves empirical knowledge use and generation. Furthermore, while all the participants demonstrated a sophisticated knowledge of SI processes and purposes, only James recognized other forms of doing SI (e.g., correlational, descriptive); however, the other participants only identified knowledge of experimental types of SI. This finding may be indicative of James's academic background as a science graduate student, whereas the other teachers had no similar academic experience. Overall, the teachers' interviews and journal entries suggest that each of them had augmented their views of SI and NOS, which in turn created some dissonance for each of them.

Domain of SI and NOS

All the teacher participants agreed to implement a project which focused on SI or NOS and, consequently, the collaborative project's purpose had a common domain for participation. At the beginning of the project it was made clear to the teachers that there would be a researcher and facilitator of the project. To this end, professional resources and references about SI and

NOS were provided and referred to frequently during the initial collaborative meetings. By the end of the first collaborative meeting it became clear that the participants were each embarking on individual action research projects. Their individual foci were personal in nature, professionally-oriented, and included the ultimate goal of engaging in practical curriculum development appropriate for their local context. This motivated the teachers to address individual gaps in their knowledge and feel comfortable negotiating entry into the collaborative group.

For instance Luke decided to participate with an open mind, interestingly, not unlike his decision to enter the teaching profession: "Action research, 'neat' to try and not think about what it's all about…[I hope to] see how it is and base my decision afterwards" (Luke, collaborative meeting #1). In contrast, Alicia saw her participation in the project as an opportunity to learn about action research, and allowed her to explore SI in-depth. In addition, she envisaged this experience as a way for her to solidify some best practices in science teaching. Similarly, James saw this opportunity as a mutually beneficial situation which allowed him to learn about action research for his future graduate research aspirations, and to enhance his understanding of NOS through sharing of his ideas and experiences. Finally, George's decision to participate in this project was based on his experiences as a new teacher, as he stated, "I am constantly reflecting and thus saw this project as a unique experience to enhance my reflective abilities and my teaching" (George, collaborative meeting #1). George described himself as having a critical perspective of the teaching profession and as a function of participating, had 'new ideas' about how students should learn science. At the onset of the project, the participants perceived teacher isolation in schools as problematic. Alicia identified this common concern of isolation:

> I think teaching is such an isolating experience that you need the continued process, and you need the continued feedback. We talked about that before, when the last time anyone was in your classroom was when you were practice teaching. You never really know in the classroom how well your ideas are coming across; whether other teachers admit it or not - it's extremely unnerving. It's one of the worst things about our profession. (Alicia, interview response)

Alicia suggested that the opportunity to participate in this action research community was beneficial because it worked to counter this isolation. She remarked in her personal journal:

> The action research project allowed problem-solving opportunities and discussions that were very helpful. The mere fact of being part of an action research group kept the project focused. The ideas and stories that others shared, even if it wasn't directly associated with my action project, influenced the direction of my project….The sharing of research and literature had untold value in the entire process. (Alicia, journal entry)

Engagement, as defined by Wenger (2000), involves negotiated and authentic participation within a learning community. Alicia's actions within the collaborative action research community exemplify the personally negotiated and authentic professional learning opportunities offered through participation in this collaborative action research community. Indeed, a common domain for collaborative inquiry gave meaning to all the teachers' actions.

Community of Science Teachers

The establishment of a trustworthy and supportive community of professionals within a high challenge and low-risk atmosphere requires clear identification of roles, responsibilities, and expectations. The participants agreed to the following expectations: examine and reflect upon their views as they relate to the focus of the collaborative action research project; attend all collaborative sessions and be punctual; support others at meetings and, if possible, outside of meeting times; be an active contributor to discussion on science education, science teaching, SI, NOS, and action research; listen actively during meetings; and engage in action research within their class. The participants were appreciative of the attention given to organizational details by the facilitator, especially at the beginning of the action research process. They acknowledged the benefits of the 'structure to support function' organization of the project, as evidenced by the following remarks during a collaborative meeting:

> Well you didn't choose the action research project for us, but you acted as a facilitator. You kept us on track in terms of our timelines and where we should be in terms of timelines. You were an additional resource when I needed suggestions. (Luke, collaborative meeting #10)

> Well for me, I saw individuals doing their own

thing and yet we could help each other. I definitely benefited from the discussion that you facilitated and your input into my approaches to things. (George, collaborative meeting #10)

In the beginning you were much more assertive in terms of us focusing on an area, the curriculum; and, as it progressed it got more into what we were doing. I think it was good to start there because I didn't even think about the provincial curriculum or NOS from an action research point of view. (Alicia, collaborative meeting #10)

The parameters, roles, and negotiated expectations established early on helped to bring cohesiveness to the community and support effective alignment to the project's domain.

All of the teachers commented on the social benefits of participating in the project. This was substantiated through the enhanced trust, support, and collegiality exhibited amongst the participants and the facilitator, the collaborative sharing of ideas and resources, and the method by which they critically and publicly reflected on ideas and confidently provided feedback on the each others' practice. James articulated the benefits of participation:

I found it very beneficial; especially to bounce my own ideas back to me was useful. It was important to think about what I wanted to do and examine my reasons and methods. It's nice to have a sounding board. I express everything verbally and out loud...that was a good experience for me. I tend to keep my 'mouth shut' for I will offend someone politically at school. This [collaborative action research group] was a way for me to be honest with myself as well as with others at the same time. (James, post-project interview)

The supportive dialectical milieu along with the low risk and high challenge context of the collaborative meetings encouraged James to participate and gave him confidence to explore his otherwise tacit views of science education. Participation within a supportive collaborative group is essential for the creation of a community of teachers. This was critical to the social development of the participants, and gives support to Wenger's (2000) recognition that a successful CoP exhibits extensive social capital and mutuality.

Collaborative Practice

The collaborative practices that occurred during the project included: sharing of classroom experiences and professional anecdotes; generation and sharing of curriculum plans and instructional actions; adapting and using new or modified teaching activities; illustrating student work generated through the action research projects. As well, the sharing of resources by the science teachers during meetings was indicative of the shift of locus of control from the facilitator to the participants and, in addition, to the trust and growing capability of the group to address contemporary and relevant science education issues. For example, Alicia provided WWW resources on 'habits of mind', which provided the group with a conceptual link between the habits and SI. George shared an old science text found in his school which helped participants to compare past textbook descriptions of SI to current ones. Luke introduced the International Baccalaureate chemistry curriculum guide that he was implementing in his chemistry class. This resource helped to illustrate the differences between the International Baccalaureate and provincial curriculum SI student outcomes. Indeed, as each meeting continued, the sense of community through the use of what Wenger (2000) refers to as *shared repertoires*—resources for sharing and negotiating meaning was common practice.

What was particularly evident was the importance of collaborative reflection and problematizing during meetings. Indeed, reflection on their individual action research projects became fodder for deeper reflection and analysis of general science educational issues. Collaborative group reflection within a critical and collegial group was paramount for all participants. Luke identified the personal benefits of these collaborative and communal reflection opportunities during meetings:

I really liked the process, and the form of getting together in collaborative action research. To hear the range of experiences...how everyone else was doing. Initially, I felt like I needed to work a little harder considering what others were doing but it forced you to stay on task. It was great, a great experience. Fortunate for us that we did get involved...unfortunate for the others that didn't. (Luke, post-project interview)

Reflection was critical for all the teacher participants because it allowed them to communicate productively and create a discourse to envisage novel curricular practices for their classrooms; and as Luke's described, the benefits of participation typify the experiences of

members of a successful CoP.

Discussion

This study illuminated the changes in science teachers' beliefs and knowledge over time due to their participation in a collaborative action research project. It was found that when the teachers began to frame their action research problems, implement their plans and share and reflect upon their actions, they began to extend their praxis as their ideas and actions became dialectically framed. Overall, each of the teachers augmented their views of SI and NOS, which in turn created some dissonance for each of them; a prime environment for belief revision and knowledge enrichment. By the end of the project, all teachers had improved, albeit uniquely, their understanding of SI and NOS; that is, they were better able to espouse explanatory depth to current SI and NOS ideas as articulated by many curriculum reform documents. This augmentation was unique to each teacher, reflecting the idiosyncratic nature of their past educational experiences, prior understanding of SI and NOS, depth of content and pedagogical content knowledge of the discipline, and mitigating constraints found at their local school. This is consistent with other research studies analyzing changes in science teachers' views and practices (e.g., Crawford, 2007; Schwartz & Lederman, 2002; Veal, 2004).

A second research objective was to describe how the group developed throughout the collaborative action research project. It can be argued that the characteristics displayed by the participants can be categorized according to Wenger's (2000) three basic descriptions of any CoP which include: domain, community, and practice. Since, the teachers' group development fits well within Wenger's descriptions, it may be suggested that a 'community of learners' was created. First, the domain condition was displayed by the participants during their participation in the project through their competence, experience and commitment to learning about current ideas in science education (i.e., SI and NOS). Second, the community condition was illustrated through their interactions. Specifically, the negotiated norms by all the group members were essential for effective collaboration and reflection, and thus allowed for competent and capable engagement by all teachers. Finally, during each collaborative group meeting, the practice condition was demonstrated by the teachers' shared routines, artefacts, and stories. Overall, the routines (e.g., meeting on a regular basis with a common format), artefact materials (e.g., textbooks, science standards documents), and communication routines (anecdotes and reflections from their classroom experiences) were utilized by all the teachers in order to be able to capably engage and align themselves to support collaboration in the domain of SI and NOS.

An overview of the activities and changes in the collaborative action research group can be overlaid with the five stages of CoP development (Wenger, 1998b): (a) *potential*, (b) *coalescing*, (c) *active,* (d) *dispersed*, (e) *memorable*. Potential refers to individuals having a common purpose and coming together. Coalescing refers to members coming together and identifying common goals and possibilities. Active refers to the stage where participants actively engage in their practice. Dispersed refers to individuals weaning their participation in terms of intensity and frequency, but the community is still an identifiable whole. Memorable refers to participants leaving behind the practice but they still remember the experience as a significant part of their professional identity. Figure 1 summarizes the evolution of this project as a CoP.

While it was necessary to establish the group, the above progression of activities was a natural and evolutionary outcome of the teachers' participation within the project.

The project evolved as a CoP, but the participants also developed individually over the course of the project. This social and individual development is perhaps indicative of a situative learning system. Situative learning theorists (e.g., Lave & Wenger, 1991; Putnam & Borko, 2000) conceptualize learning as changes in participation in socially organized activities. Other researchers (e.g., Cobb, McClain, Lamberg, & Dean, 2003; Driver, Leach, Millar, & Scott, 1996) have characterized learning as having both individual and sociocultural features and describe learning as being both enculturation as well as construction. Thus, changes in teachers' beliefs and knowledge in this study are an outcome of the individual teachers' participation in this collaborative action research project. In particular, the teachers' development over time may have been a consequence of their mutual discourse, modification of their views with respect to the common domain of SI and NOS, and development and negotiation of their teaching repertoire and curriculum products from their action research projects. As Wenger (1998a) proposes:

> This two-way interaction of experience and competence is crucial to the evolution of practice. In it

Potential	Coalescing	Active	Dispersed	Memorable
Common focus; sharing of similar curriculum issues and reflective dispositions; commitment to engage in action research.	Explore science curriculum ideas, scientific inquiry and nature of science knowledge; share and reflect on practice; negotiated involvement in group; autobiographical reflection.	Plan for classroom actions; critical discussion and feedback; plans for future actions; collaborative problem solving and communal reflection on and about practice.	Communicating and sharing of ideas; professional collegiality; plans for the production of common products (e.g. journal dissemination, conference presentations).	Preserving of artefacts and documents; strong episodic memories of collaborative events; empowered to engage in future communities of practice and professional development activities.

(time)

Beginning of Project *End of Project*

Figure 1. Evolution of the collaborative action research project.

> lies the potential for a transformation of both experience and competence, and thus for learning, individually and collectively. (p. 139)

In essence, the relationship between their competencies and experiences during the project propelled their personal and professional development.

Implications for Science Teacher Development

Teacher development may be regarded as a crucial leverage point to affect change in the classroom. A collaborative action research project can provide teachers with an opportunity to immerse themselves in a topic, challenge their implicit views, and develop novel pedagogical practices. The findings from this study align with the claim (Garet, Porter, Desimone, Birman, & Yoon, 2001) that the participation of groups of teachers from the same school, subject, or grade helps to establish both coherence and active learning opportunities which, in turn, are related to improvements in teacher knowledge and skill, along with changes in classroom practice. For schools, therefore, the organizational loci for the potential development of a CoP for science teachers are science departments within secondary schools, and grade groupings (e.g., Grades 3-5 and 6-8) within elementary and middle schools. Each community would require the support and leadership of a facilitator. School district science coordinators and university faculty are well-positioned to facilitate science teachers in this type of professional development endeavour.

Many recommendations for effective science and mathematics professional learning require job-embedded and school-supported teacher development opportunities (Loucks-Horsley et al., 2003). Furthermore, Wilson and Bearne's (1999) examination of research on teacher development and professional knowledge acquisition states that all successful development projects involved: communities of learners, teacher knowledge constructed in the context of its use, and critical colleagueship. Collaborative action research exhibits many of these successful teacher development characteristics. A situative perspective on teacher development, characterized as a meaningful negotiation between practice and products within a community of practitioners, is a useful framework to analyze teacher development. Furthermore, it can be constructive in the design, implementation, and analysis of other collaborative teacher development endeavours which aligns with current science reform initiatives.

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Preparing Pre-Service Teachers to Teach Mathematics in Inclusive Classrooms: A Three-Year Case Study

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Federal and state regulations mandating inclusion of students with disabilities in general education classes have made it essential to create pathways for pre-service teachers to develop skills to teach content to diverse groups of students. The study uses a framework suggested by the relationship between teacher attitude and teacher behavior (Fullan, 1982), teacher beliefs and practice, and self-efficacy and behavioral change (Bandura, 1977). The purpose of the study was to examine changes, if any, in three cohorts of general education teacher candidates' (n=13, n=8, n=5) attitudes toward teaching mathematics to students with disabilities after participating in focused instructional experiences which provided both information and vicarious positive teaching activities in special education. Data collected included pretest and posttest scores for each of the three cohorts and journal entries. Little or no change in attitude towards students with disabilities and mathematics, and efficacy to teach students with disabilities was observed for the year one and year two cohorts. In the third year the modules were combined with a structured field experience. The data collected from the third year cohort suggested a positive trend in attitude as measured by the survey data and field experience journal data. Future study with larger samples is needed.

The landscape of the classroom has been transformed to a garden of students from different backgrounds, levels of abilities, and challenges. Please consider the following statistics. Over six million students, ages 6-21, receive special education services in the United States. This constitutes about 13.7% of the total school-age population (U.S. Department of Education, 2006). Of this student population, 96% are served in general education school buildings. In the United States more than 80% of public school teachers have students receiving special education services in their classes (Editorial Projects in Education, 2004).

Now consider the following educational mandates. The reauthorization of Individuals with Disabilities Education Act, 2004 (IDEA) directs that students with disabilities be placed in the least restricted environment (LRE), and participate in state and district testing systems. No Child Left Behind of 2001 (NCLB) holds schools, districts, and states accountable for testing at least 95% of students with disabilities, while ensuring that these students perform at the same "proficient" level on state tests as typical students.

In addition, the National Council of Teachers of Mathematics (NCTM) *Principles and Standards for School Mathematics* includes *The Equity Principle*. *The Equity Principle* states that "Excellence in mathematics education requires equity - high expectations and strong support for all students" (NCTM, 2000, p. 12). This principle makes clear the idea of meaningful mathematics experiences for every student. The legislation cited, the standards movement, and the NCTM principles have brought dramatic changes to the classroom by mandating the inclusion of all students in the general education classroom. The new heterogeneous make-up of classes includes children formerly in special education classes. These children not only have different learning styles, but process information differently than typical students. These changes suggest that teachers need to possess the skills and dispositions to teach a diverse group of students in inclusive settings.

As a result of all of the factors mentioned, the researchers chose to examine the outcomes of embedded instructional modules about teaching mathematics to students with disabilities, on general education pre-service teacher candidates in a mathematics methods class. Over three years the researchers looked at change in pre-teachers' perceptions of their skills and sense of efficacy to teach mathematics to students with special needs after participating in a focused instructional ex-

perience.

Review of the Literature

The Curriculum Challenge of the Inclusive Classroom

More students with disabilities are taking standardized tests in mathematics, but performance indicates many are not achieving passing scores. New York State Education Department (2001) reported an increase in the number of students with disabilities included in state and national assessments. For example, at the secondary level, 5776 students with disabilities took the Regents Examination in Mathematics Course 1 in 1997. This population increased to 15,348 students with disabilities taking the examination in 2000. The percentage of students with disabilities achieving the typical passing score of 65 was disappointing and decreased from 46% in 1997 to 37% in 2000.

While more students with disabilities are taking assessments, they are not achieving passing scores at the same level as their typical peers. The tests prove more challenging for this population as they continue through the grades. For example, the number of passing scores on the New York State Mathematics Assessments decreased from the fourth grade to the eighth grade for students with disabilities. In state testing in 2002, the performance of students with disabilities at both the fourth grade and eight grade levels was lower than that of typical students (NYSED, 2004). On the fourth grade assessment 46% of the students with disabilities received a passing score, while at the eighth grade level that number decreased to 16%. New York State and national outcomes show that the number of passing scores on standardized assessments for the general population is increasing. According to The National Center for Educational Statistics (Lee, Grigg, & Dion, 2007) the results in 2005 of typical students on the NAEP assessment in mathematics was higher than any previous year.

To ensure that all students make progress and achieve rigorous standards, teacher candidates and working teachers must gain a sense of accountability as well as efficacy in teaching both mathematics and teaching students with disabilities.

Preparing Teachers to Meet the Challenge

Teacher candidates report not feeling prepared to teach students with special needs. This sense of inadequacy translates into teacher candidates not experiencing a sense of efficacy in teaching in the inclusive classroom (Wideen, Mayer-Smith, & Moon, 1998). Bandura (1977) theorized that for individuals to gain proficiency or to perform a task, they must develop the requisite skills to successfully complete the task. They must also possess the confidence that they can effectively use these skills. Maccini and Gagnon (2002) illustrate Bandura's theory in their discussion of the NCTM Principles and Standards by pointing out how teacher beliefs about efficacy, and their sense of understanding of the Principles and Standards, may affect the actual application of these standards in the classroom.

Teachers' perceptions about the curricula content and the type of students they are teaching can relate to their beliefs about teaching and learning as well. Their beliefs about their students and their own sense of efficacy in teaching are critical components of successful change that will benefit their students. Therefore the researchers looked to Fullan (1999) for the theoretical framework of this study to begin the conversation on the connection between changes in teacher candidate's beliefs and educational change.

Fullan (1999) states, that there is a tendency to keep people that are different from us at a distance. Diverse groups of students, including some with disabilities, are now part of every teacher's classroom. The discomfort that teachers may have with students who are different must be addressed to create an instructional environment that will not interfere with student learning. Teacher preparation plays a key role in looking at this issue. Fullan states that quality teacher preparation involves "developing and applying knowledge of curriculum, instruction, principles of learning, and evaluation needed to implement and monitor effective and evolving programs for all learners" (p.115). He believes that teacher education means working with all students in an effective way that respects difference. These values are particularly pertinent today with the move toward more inclusive education. The confluence of the current educational challenges has instigated a complex change process in schools. Stacy (1996) explains that complicated systems such as schools interact according to rules that require participants to examine their behavior and improve it. By improving or changing individual behavior, the behavior of the entire organization changes. The idea of beginning at the pre-service level to improve teacher instructional behavior carries with it the hope that these changes will be carried over into schools.

Method

This descriptive case study began as an examination

of an effort to improve teacher candidates' attitudes and skills toward teaching mathematics to students with disabilities. The study took place over three years with three different cohorts of teacher candidates enrolled in a one term general education undergraduate mathematics methods course.

The research methodology of this study is aligned with the Discovery Research method identified by Raider-Roth (2005). This genre of research requires that the researcher locate the primary issues and paths of future studies, constant comparison of the data, and examination of the outcomes key ideas that increase understandings and raise questions for future study. Raider-Roth's theories advocate following one's own research questions and as one evaluates the data to continue to refine them and deepen the research process. This study presents outcomes that are primary issues and will lead to further studies with larger populations.

Case studies arise from a desire to understand complex social phenomena. "This tradition of inquiry allows an investigation to retain the meaningful characteristics of real-life events." (Yin, 1989, p. 14). Yin discussed three dominant modes of data analysis in case study research. The first being the search for "patterns" by comparing results with patterns predicted from theory. Second, "explanation building" whereby the researcher looks for causal links and/or explores plausible or rival explanations and attempts to build an explanation about the case. The third dominant mode being "time-series analysis" whereby the researcher traces changes in a pattern over time. The researchers used this theoretical foundation to guide their work.

The researchers examined evidence over three years to answer the question, "After participation in a focused instructional experience and a structured field experience, what are the changes, if any, in pre-service teachers' attitudes and beliefs about teaching mathematics to students with special needs?"

In year one, a pilot study was conducted to field test two modules; one in skills to teach mathematics, and one in skills to teach students with disabilities. The modules were two hours and fifty minutes in length and implemented during two regularly scheduled weekly class sessions of a fourteen week undergraduate course. Data analyzed at the end of the pilot was used to guide refinements implemented in year two and three of the study.

In year two and three the study was repeated with refinements. The content of the two modules was revised and an additional module of the same length was added. Revisions included the integration additional mathematical strategies to increase skills. A video about a child with disabilities was incorporated to improve the teacher candidates' understanding and empathy toward students with differences. A further refinement was added in year three of the study. Students in the first and second year of the study participated in a 20 hour field experience in a school setting of their choice. A structured field experience was built into the third year of the study placing the pre-service teachers in a special education setting to give them the opportunity to apply the skills they were learning by tutoring students with disabilities in mathematics.

Sample

The teacher candidates in the sample were matriculated students in an elementary general education program leading to certification in grades 1 through 6. All participants in the study were second semester juniors or first semester seniors enrolled in a mathematics methods course. In year one, the sample was made up of 13 (12 female, 1 male) undergraduate teacher candidates. The year two sample consisted of 8 teacher candidates (6 female, 2 male), and in year three, 5 teacher candidates (4 female, 1 male).

Instrument

In year one of the study, the researchers created a pilot survey with a total of twenty items which was used as a pretest and posttest. The survey examined attitudes and beliefs about each of four constructs: attitude toward students with disabilities, self efficacy about teaching students with special needs, attitude regarding teaching mathematics, and self efficacy about teaching mathematics. The survey used a five point Likert scale: strongly agree, agree, undecided, disagree, and strongly disagree using the numbers one through five respectively. A score of "one" indicated the most agreement with the item a score of "five" indicated a strong disagreement with the item. Content validity of the survey items was reviewed by a panel of three experts who were professors in the School of Education in one of the researchers' institution.

Procedure

Initially two modules of instruction for the course were created by the researchers to address the Content and Process Standards identified by the National Council of Teachers of Mathematics (2000), and strategies to teach mathematics to students with disabilities (Butler, Miller, Lee, & Pierce, 2001; Corral & Antia, 1997; Jitendra & Xin, 1997; Salend & Hofstetter, 1996). At the beginning of the semester the students were informed

that for several sessions of the course, the class would be co-taught by their professor and a visiting professor from another college. The content of the modules was described on the course syllabus. The survey pretest was given to each student before the first module was taught. The same survey was given to each student after the last of the study module was presented. Students were told that the results of the survey were confidential and anonymous and they did not have to participate in the survey if they chose not to. The researchers did not know the names of the students associated with responses.

The modules provided performance desensitization in working in the mathematics curriculum and applying special education strategies for lesson planning. In the second and third year, the modules were expanded to three. Below is a brief description of each module.

Module One.

- A short history of instructional practices in mathematics
- The content and process standards of the National Council of Teachers of Mathematics (NCTM, 2000)
- Areas of mathematics skills students need to be successful in a mathematics
- Traits to look for to identify students with low cognitive ability and learning disabilities were identified
- An examination of a work sample distributed to the class, analysis of the error pattern and strategies to assist the student

Module Two.

- NCTM's *Learning Principle,* and *Assessment Principle*
- Four types of mathematical instructional activities
- Developmental activities used to build a new idea
- Practice activities for new concepts
- Application activities in an authentic setting
- Assessment activities for students to demonstrate in an observable way their depth of understanding
- Alignment of instructional strategies with student needs
- Review of traits to identify students with mathematical learning disabilities

After reviewing the data from the first year and reflecting on the lack of change in attitude and beliefs toward teaching students with disabilities, a third module was created by the researchers.

Module Three

- Overview of Piaget's Four Stages of Mathematics Concept Development
- Expanded discussion of the identification of processing issues
- Areas of non-mathematics skills students need to achieve in mathematics
- Expansion with examples of the four types of mathematical instructional activities; developmental, practice, application, and assessment
- Viewing of a documentary video of a young girl, Lily, with Down Syndrome which allowed students to see a child with a disability in a number of different venues including mathematics instruction

During the third year of the study the researchers reviewed the data from the first two years and returned to the literature on change of attitudes and belief in teacher candidates. As a result of this review a structured field experience component was added to the course. Teacher candidates were assigned to tutor a student with disabilities in mathematics for a period of 20 hours. They were asked to keep a journal in which they described the students they worked with, the strategies they tried, the outcomes of the strategies and their reflections of the experience of working with students with disabilities.

Results

The data examined in this study were pre and posttest scores and journal reflections of the third cohort. There were no non-respondents on the survey for any of the three cohorts of teacher candidates in the sample. Every survey was completed with a response to each item. At the conclusion of the second year, the survey was revised to make the items more closely aligned with the knowledge base presented and the focused field experience. As a result, three items were kept on the third year survey verbatim. Table 1 lists the survey items included.

The means of the pre-service teachers' scores were calculated by survey item and were aggregated by construct to create a construct mean score for the sample.

The pretest/posttest means in year one for the items that indicated negative attitudes toward students with disabilities were 3.55 and 3.55 respectively indicating an aggregated mean between undecided and disagree for these items. The pretest/posttest means for the items relating to self perceived efficacy to teach students with disabilities was 1.97/1.97 between strongly agree and agree. Means on items in the construct, attitudes toward teaching mathematics, was 2.17/2.17, and the means on items relating to the self efficacy was 2.22/2.20. In summary, the pretest and posttest scores on the first three constructs showed no change and very

Table 1
Pre- and Posttest Aggregated Mean Scores by Item, Year One, and Year Two

Item	Year 1 Pretest	Year 1 Posttest	Year 2 Pretest	Year 2 Posttest
I am comfortable with people with disabilities.	2.0	2.0	1.8	1.6
I think students with learning disabilities take too much of a teacher's time when placed in a general education classroom.	3.1	3.1	3.6	3.75
I am uncomfortable around students with disabilities.	3.8	3.8	3.0	3.4
I act differently around students with disabilities.	3.4	3.4	3.0	3.4
I feel nervous around students with disabilities.	3.9	3.9	2.8	3.4
I feel comfortable teaching students with disabilities.	2.4	2.4	2.4	3.2
I feel capable of differentiating classroom instruction to meet the needs of all my students.	1.7	1.7	2.0	2.4
I know instructional strategies that are effective for instructing students with disabilities.	1.9	1.9	3.0	2.2
I know how to provide accommodations for students with disabilities.	1.9	1.9	3.4	3.0
I like the idea of teaching mathematics to my future sttudents.	2.6	2.6	1.8	1.8
I like learning about mathematics.	2.1	2.1	2.0	2.0
I want to learn more about teaching mathematics to elementary students.	1.4	1.4	1.6	1.4
I believe I know enough mathematics to teach it to elementary students.	2.6	2.6	2.6	2.2
I believe I can create a lesson plan that addresses at least one of the NCTM process standards.	1.9	1.9	2.4	2.2
I am uncomfortable when I think about teaching mathematics to my future students.	2.9	2.9	3.8	3.2
I know instructional strategies that are effective for teaching mathematics to elementary students.	2.4	2.4	2.4	2.4
I believe I can teach a lesson that addresses at least one of the NCTM content standards.	1.8	1.8	2.2	2.2
I know at least 2 of the 6 NCTM principles of school mathematics.	2.1	2.1	3.0	2.4

minimal change on the last construct self efficacy for teaching mathematics.

The same instrument was used in the second year of the study. Means were calculated for the pretest and posttest responses. The means were then aggregated into means for each construct. The construct means score for negative attitudes toward students with disabilities changed from 3.1 to 3.43 indicating a trend toward disagree from neutral. The construct mean score for self efficacy for teaching students with special needs showed minimal change from 2.7 to a slightly more positive 2.65. The mean score for the construct, attitude toward teaching mathematics moved from 2.16 agree to a slightly less positive 2.27. The aggregated mean for self efficacy for teaching students mathematics went for a 2.74 to a more positive 2.3.

Participants agreed with the statement that they were "comfortable around people with disabilities" in both year one and year two. They also agreed with the statements regarding feeling capable about differentiating instruction to meet all students' needs. The instructional strategies presenting in year one and year two did not change their perception of their capability to use differentiated strategies.

Table 2
Pretest and Posttest item Mean Scores of Pre-service Teacher Candidates for First (n=13), Second Year (n=8), and Third Year (n=5) of Study

Item	Year 1 Pretest	Year 1 Posttest	Year 2 Pretest	Year 2 Posttest	Year 3 Pretest	Year 3 Posttest
I know how to provide accomodations for students with disabilities.	1.9	1.9	3.4	3.0	2.3	1.8
I like the idea of teaching mathematics to my future students.	2.6	2.6	1.8	1.8	2.0	1.5
I know instructional strategies that are effective for teaching mathematics to elementary students.	2.4	2.4	2.4	2.4	2.3	2.0

During year one, the participant responses to attitudes toward mathematics showed positive scores and minimal change. In year two, the participants agreed with positive statements about mathematics and after participating in the modules showed a trend toward greater self efficacy regarding teaching mathematics to students with disabilities. The year two modules had minimal if any effect on how the participants felt toward mathematics. In year three, participant responses appeared to show a trend toward positive change in attitude and beliefs about teaching mathematics to children with disabilities. This was supported by the narrative reports from teacher candidates. Table 2 describes the responses of the pre-service teachers on the items that were repeated verbatim on the pre-test and post test in year three.

In year three, qualitative data was collected from candidates participating in a focused field experience. The journals of the teacher candidates' field experiences were coded and examined for patterns and trends. The data from the third cohort of teacher candidates indicated a change in attitudes toward teaching mathematics to students with disabilities. There was also an indication of a change in their own confidence level. One teacher candidate reported "the experience opened her eyes". Another commented, "For the first time I truly got an idea of the difficulties that special education students have".

All the teacher candidates' comments indicated a sense of pride as to their accomplishments during in the experience. One teacher candidate remarked,

> I remember the teacher saying "J has never worked so hard in his life before Miss G. came." This comment from the teacher gave me the confidence that I needed to pursue my career as an educator and let me know that I successfully completed the job that I was there to do. (Teacher Candidate 2)

All teacher candidates indicated that the experience had given them increased confidence in themselves. The following comment is representative of the reported increase in confidence,

> First coming into the classroom I was very nervous because I myself was not very good in math. Having to teach someone math overwhelmed me because I was afraid I wasn't going to be able to give W. the help he needed. So not only did W. have little confidence in himself when it came to math but so did I. I of course did not let W. know that. When leaving I knew that W. gained confidence in himself and he also made me gain confidence in myself, which I am thankful for. This experience was one of the better ones because I never came out of a classroom and felt I helped anybody. This experience was nothing but rewarding. (Teacher Candidate 3)

All teacher candidates indicated the experience teaching mathematics to a student with disabilities was a positive one. One teacher candidate expressed it this way,

> As I look back on this case study, I am amazed of how much I have learned. I feel so lucky to have been able to work with such a fantastic teacher and school district who gave me an opportunity to work with such great children. The strategies and math concepts I taught gave me valuable experience working in a real class setting. However, the most valuable aspect that I can take out of this field work is the hands on experience that I received. I feel that I have learned so much in terms of intangibles; I am so much more confident heading into my future years. This course has given me so much and so many wonderful ideas that I now have such

> a great feeling when it comes to teaching mathematics. (Teacher Candidate 1)

The results of the study suggest that in years one and two the self reports of the pre-service teachers on the pre and post test surveys did not document any evidence of a change in the attitudes and beliefs about teaching mathematics to children with disabilities. The self reports in the third year in pre-service teacher journals suggest a trend toward increased self efficacy and confidence toward teaching mathematics to identified children.

Discussion

This study examined three groups of pre-service teacher candidates' self-reported attitudes and sense of efficacy in two areas; mathematics, and teaching mathematics to students with disabilities.

The literature indicates that limited information about students with disabilities increases teacher fear, anxiety, and general discomfort in working with these students (Avramidis, Bayliss, & Burden, 2000). Some of this attitude results from a feeling of lack of preparation for teaching students with disabilities (Cook, Tankersley, Cook, & Landrum, 2000). Attitudes toward teaching mathematics also reflect increased need for additional instructional support (Graham & Fennell, 2001). Upon completing an analysis of the surveys, the researchers determined that the sample began with positive attitudes toward students with disabilities, and showed little or no change in their attitudes after participating in the instructional modules during years one and two.

The lack of change or minimal change in dispositions toward teaching students with disabilities in the first two years pointed to a need to revisit the special education portion of the module. Additional activities, such as more in-depth explanation of strategies, and the showing of a video of the school experience of a girl with intellectual disabilities were added which resulted in a third module. In the third year, a focused experience further allowed students to link theory and practice in a field experience.

The researchers recognized that positive attitudes towards students with disabilities and toward mathematics instruction represented only part of preparation needed by teacher candidates. Cook et al. (2000) found that positive attitudes alone do not result in successful student outcomes. Positive attitudes alone cannot compensate for insufficient preparation. Andrews and Clementson (1997) argue that pre-service teacher candidates need to become involved with students with disabilities not just be provided with information to increase positive attitudes. As a result, in year three, a field component was created that provided the opportunity to work with students receiving special education services. The more promising results from year three highlight the impact of the field experience. It allowed students to synthesize, apply, and reflect on the knowledge presented in the modules and make the connection to working in an actual classroom with students.

Conclusions

A study by Campbell, Gilmore, and Cuskelly (2003) found that increased positive attitudes toward students with disabilities resulted from participation in a full semester course that included structured field work experiences and formal instruction. The third year results of this research confirm that finding. When additional classroom study and an integrated field experience are integrated with the knowledge base, teacher candidates' report increased positive attitudes and a greater sense of self-efficacy. Since this study was designed as a descriptive case study, the findings cannot be generalized. However the outcomes of this case study can serve as a guide to further research. Larger samples and random selection should be used to test the theories that emerged from the data; specifically, the effect of a structured field experience with students with disabilities for general education teacher candidates should be examined.

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RESEARCH IN
the classroom

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Understanding the Affects of Audience on Mathemtaical Writing

This study formally explored how high school students addressed audience when they wrote mathematically. Student explicated the solving of a mathematics problem to their mathematics teacher and their English teacher. This study showed that students did change the style and language of their mathematical writing as their audience changed. It adds knowledge and support to current ideas of teacher presentation during routine daily instruction. Also included are implications this information may have on mathematics education.

On the surface, mathematics and English courses may seem disparate content areas, especially at the secondary level. However, upon further examination, when comparing the writing in mathematics and English, they can be very similar. Both consist of symbols, and through the combination of these symbols, meanings are made (Harris, 1995). Also, both have subject-specific vocabulary and grammar, and its meaning is dependant on its context within the text (Harris; Usiskin, 1996). As a teacher who taught mathematics and English, I had many opportunities to informally observe my students' use of writing in both content areas. One idea that struck me was audience. My students who had me as their mathematics and English teacher wrote differently than those students who only had me for their English teacher. I talked with other member of the mathematics department, asking them what kinds of writing they received. What I informally learned was that my mathematics students wrote differently than the students in my colleagues' classes.

I often heard this statement, "Our kids can't write" from my mathematics teachers. These teachers incorporated writing assignments in their routine lessons, but they didn't model how the students were to write these assignments. Essentially, the mathematics teachers expected their students to write to them as the students would write in their English classes. Primarily, I wanted to show teachers that students are emulating the kinds of writing that was presented to them.

With this informal information, I decided to create a study, using two different classes, an English class and a mathematics class, to see if similar differences occurred. By studying two different classes, I was able to be more objective in the data collection and analysis. Through this study, I wanted to show mathematics teachers that what they present, in their daily routine instruction, influences the mathematical language their students use. Current trends are to incorporate writing assignments in the mathematics lessons. Through writing, students would be able to explore mathematical concepts and ideas. What is lacking is research on the mathematics teachers' influence over the students writing styles and the students' use of language. Essentially, I wanted to show mathematics teachers that if they wanted their students to write a certain way, then the teachers need to model that format and method.

Research Questions

There are aspects of mathematics and writing that were similar. For this study, I chose to focus on one aspect: the role of audience in the students' writing. As a result, my research questions were:

- What kind of mathematical language is used in mathematics class and English class?
- How does this language change as the audience/teacher change?

Current Foundations of Mathematical Writing

Understanding written symbols is very important in the teaching and learning of mathematics. In order to be accepted into the mathematical community, it is important for mathematicians be able to manipulate mathematical language, especially in written form (Burton & Morgan, 2000; Pimm, 1995). As a result, the writer will conform his/her writing to what the audience wanted to read or is capable of reading. At the high school level, it is unclear if the students are manipulating mathematical language in order to be accepted into the mathematical community. In most mathematics classes, students are asked "to *record* their mathematics

rather than write it" (Pengelly, 1993, p. 14). What has been shown is that students change their writing in English class in order to conform to the perceived expectations of their audience; therefore, what is known is that students will modify their writing in order to give what the teacher wants (Gilbert, 1989). Ede and Lunsford (1984) stated that writers create their audience, and if they want their information to be read, they need to adapt to the needs and expectations of their audience. Writers will determine their audience before writing their text (Long, 1980). Also, an audience existed when there was a specific social relationship between the writer and reader, and when there was a specific function to the writing that was exchanged (Park, 1986).

Current mathematical writing research primarily focuses on the mathematics of text. Primarily, the focus is on three areas: acquisition and retention of mathematics skills (Birken, 1989; Jundak & Zein, 1998), the understanding of students' metacognitive processes in solving mathematics problems (Lax, 1989; Powell, 1997; Pugalee, 2001), and the awareness of the students' affective processes in mathematics class (Baxter, Woodward, & Olson, 2005; Borasi & Rose, 1989). Whether the students is writing their fears towards mathematics or writing an explanation of solving a mathematical problem, the emphasis has been on the mathematics. Current reform efforts have put a focus on the cognitive processes of solving the mathematics problems. It calls for a student-centered environment where students can discern and solve problems. Students need to learn how to understand the concepts that are presented in the mathematics, not just go through the motions of solving the problems to satisfy the teacher (McKinney & Frazer, 2008; Smith, 2000).

The focus of this study was on the students' use of language when writing about mathematics. There is a distinct audience embedded in the study's design: a mathematics teacher, an English teacher, and a friend. Even if the same students are involved with the different audiences, socio-cultural environments differed, because the context of each class changed as the academic subjects and teachers changed.

A mathematics class is a community, and in order for this community to function, there needs to be communication amongst the members of the community. For communication to occur, all of the members of the community need to have prior knowledge and an understanding of the accepted mathematical conventions. Whether informal or formal language is used in conveying the information, the accepted meanings of the mathematical conventions, in the form of symbols and content specific vocabulary, stay constant. Certain assumptions are made when one mathematician (i.e. students) writes to another mathematician (i.e. teacher). This writing is a by-product of the assumptions, which are either said or unsaid by both parties. Understanding students' attention to audience is important, because it is necessary to understand how teachers influence their students.

High school students are primarily taught mathematical writing through their mathematics teacher. The mathematics teacher is the authoritative voice in the classroom. Through the teacher's instruction, students will be exposed to how the mathematics teacher uses writing in the classroom. In turn, the student will try to emulate the teacher's mathematical writing usage. In my experience, these students were conscious of what was expected of them, because they equated conformity with a positive grade.

Methodology

This study was a mixed methods investigation of students' mathematical writing and how it changed in relationship to audience. I used qualitative methods in collecting my data, and I used content analysis to identify qualities of writing that various clusters of writing samples appeared to share, examining writing samples that seemed to share common characteristics or qualities.

Research Participants

Thirteen students participated in this study who attended a suburban, parochial high school. They were Caucasian-American high school sophomore (grade 10), between the ages of 15 and 16 years old. 62% of the students were male, and 38% were female. These sophomores were the only participants in my study, because they had either Mr. M. (the mathematics teacher) or Mr. E. (the English teacher) as instructors. Five of these students only had Mr. M as their teacher; four students only had Mr. E. as their teacher, and four students had Mr. M and Mr. E. as their teachers. These thirteen students were evenly distributed between Mr. M's and Mr. E's classes.

Sophomore students were used because Mr. M. only taught sophomores. Mr. M. and Mr. E. were chosen because they were the most qualified. In the mathematics department, many of the teachers did not have proper content area certification. Thus, both were established teachers in their respective fields, having

proper certification and pedagogical experience to teach their content areas. Within the English department, many were not comfortable giving a mathematical writing assignment as part of their daily routine classroom instruction. Mr. E. felt comfortable. As a result, only Mr. M. and Mr. E. agreed to be a part of this study.

Writing Prompts

Students were given writing prompts which I designed in both the mathematics and English classes. Two of the prompts were written in Mr. M's style, two were written in Mr. E's style, and two were written in the style of a friend. All of Mr. M's writing prompts followed the same format as his in-class writing assignments: a space for the student's name in the upper right hand corner, the word "worksheet" in its title, the mathematical problem to be solved in the center of the page, and the phrase "show work" in the worksheet's instruction. Writing prompts in Mr. E's class followed his format: a space for the student's in the upper left hand corner, the title "In-Class Writing Assignment" centered at the top of the page, and the topic of the writing assignment (i.e. mathematical problem and its explanation) below the title.

Writing prompts to a friend took on two forms. The first form was in the format of an informal note, typical of what high school students give to one another. This prompt was handwritten, on lined notebook paper, with casual language. In the second form, it took on the format of an electronic mail message. The language was still informal, similar to what adolescents would send when seeking help on their homework. With all of the writing prompts, the mathematics problems were the same. The values changed from assignment to assignment, but the mathematical concepts stayed constant.

Procedures

After obtaining permission from the students to examine their writing, I gave the teachers several directives. The first was to distribute the writing prompts, which I had written, as part of their routine, in-class writing assignment. I told them that they could use them in any manner, but I did not tell them how to present the writing prompts. Also, I asked them not to tell the students that the writing prompts came from me. In fact, I specifically stated, "Incorporate them [writing prompts] as naturally as possible."

All of the writing prompts were given two or three days apart, within the same week, over a four week period. Once they were completed, I asked the teachers to give me Xeroxed copies of all of the students' responses to the writing prompts before they graded the papers. Once I received the copies, I asked the teachers to grade the writing prompts as part of their routine assessment. I did not give the teachers a grading guide or rubric. Rather, I wanted the teachers to assess the writing samples as if it was part of the class' routine instruction, thus making the data collection process as natural as possible.

The first set of writing prompts were given the first week of the study. The English was given one writing prompt, and the mathematics teacher received two: One was written as if the teacher wrote the assignment, and the other was written as if a friend wrote a personal note to the student. Using the writing prompts as review exercises for an upcoming test, Mr. M. agreed to not distribute the prompts two days in a row. He agreed to give the prompts, skipping one day between them. Two weeks later, another set of writing prompts were administered. In this case, the mathematics teacher received one writing prompt, and the English teacher received two writing prompt: One was written in the style of the teacher, and the other was written in the style of an electronic mail message. Just as with the mathematics teacher, the English teacher agreed to give the prompts, as routine in-class writing assignment, skipping one day between them. With both teachers, they distributed the prompts within the same week, and both used the prompts as in-class writing assignments at the beginning of class.

During the third visit, I returned to the school and videotaped the teachers during their instructional lesson. In the videotaping, I focused on the teachers' routine classroom instruction. Primarily, I wanted to record how they used writing in their routine instruction. At the same time, I wanted to understand the students' learning environment for each class. As a result, when there were no students in the room, I videotaped the walls of each classroom. I wanted to know all of the kinds of writing that the students encountered during their mathematics and English lessons.

Data and Analysis

Since this study explored the nature of students' mathematical writing and how it changed according to audience, I devised a coding scheme that allowed me to classify the students' writing into different categories. First, after examining the writing samples, I noticed two main kinds of writing and clustered them into two groups: mathematical writing with equations only and mathematical writing with equations and scripted long-

hand. Then, I examined each cluster and noticed that the cluster of mathematical writing with equations only all looked similar. All of these samples had a series of equations with "=" connecting the two parts of the equations. On the other hand, the cluster of mathematical writing with equations and scripted words could be further categories into three different categories: Category A showed a distinct separation of scripted sentences and equations; Category B had equations, but the scripted sentences contained individual logograms and numbers embedded into the text, and Category C had full equations embedded into the scripted text. In Category C, the embedded equations acted like scripted sentence, and they added meaning to the text.

Once I identified the categories, I compared the students' writing samples to the qualities of writing the students encountered in their instructional environment. Focusing primarily on the scripted words that accompanied the equations, it was clear to me that the students' writing samples displayed distinctive qualities.

Category A—Scripted Longhand Only. There were five writing samples in this category. This category had scripted longhand used as definitions and directives. With these writing samples, students only wrote one verbal sentence that accompanied their equations.

For example, in Figure 1, the student wrote a series of mathematical sentences. The first one starts with $3y = 96$, and there are a series of sentences, in the form of equations, that explains how the problem was solved. Unlike the typical sentence, there is no punctuation at the end of each one. In addition to the mathematical sentences, this student wrote a fourth sentence that consisted of only words. This fourth sentence added clarification to the mathematical functions that were executed, and it contained words that had mathematical connotation to them ("equals," "gives").

The writing in Figure 2 is another example of Category A. In this category, students wrote complete scripted longhand sentences that were separate from

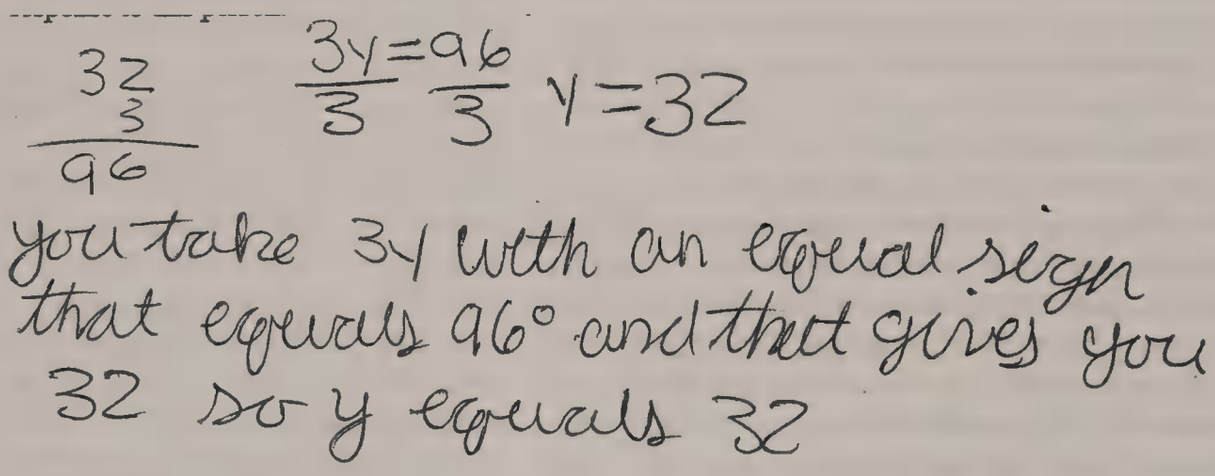

Figure 1. Student writing sample of category A.

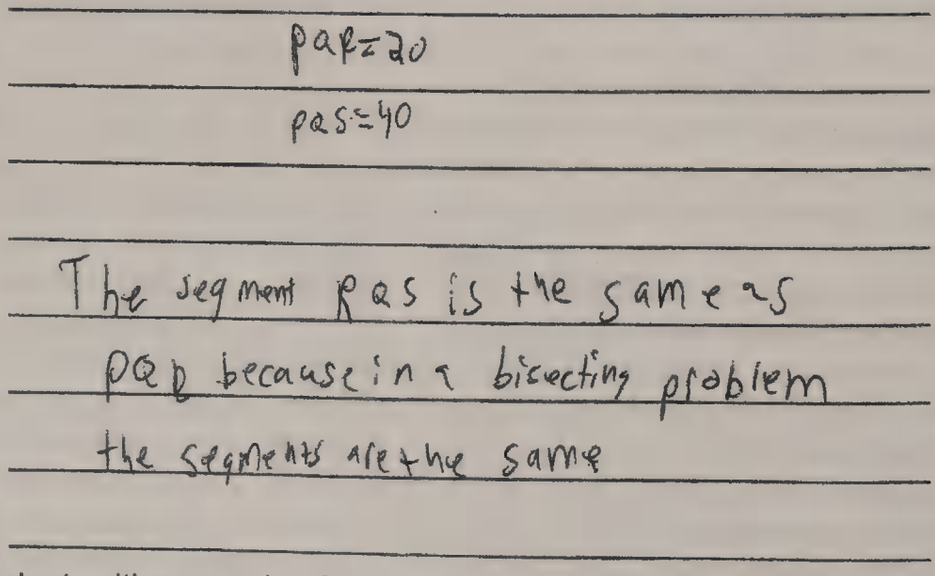

Figure 2. Another student writing sample of category A.

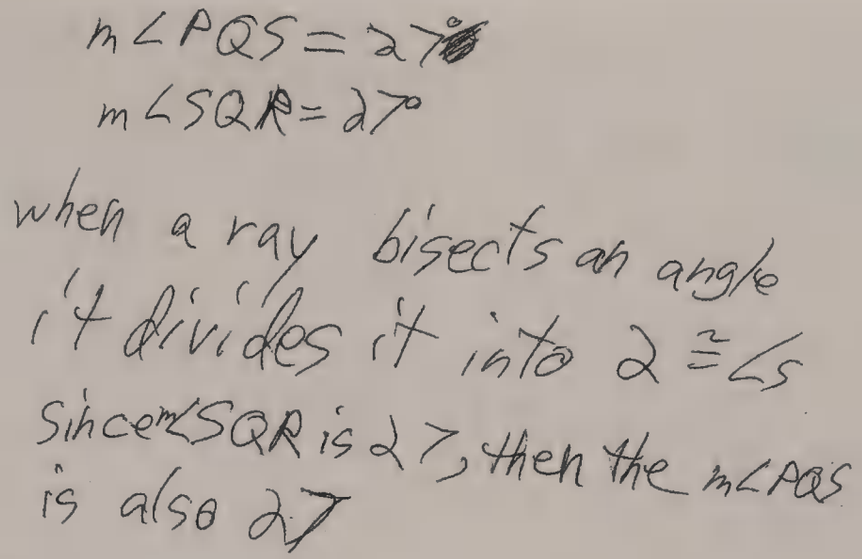

Figure 3. Student writing sample of category B.

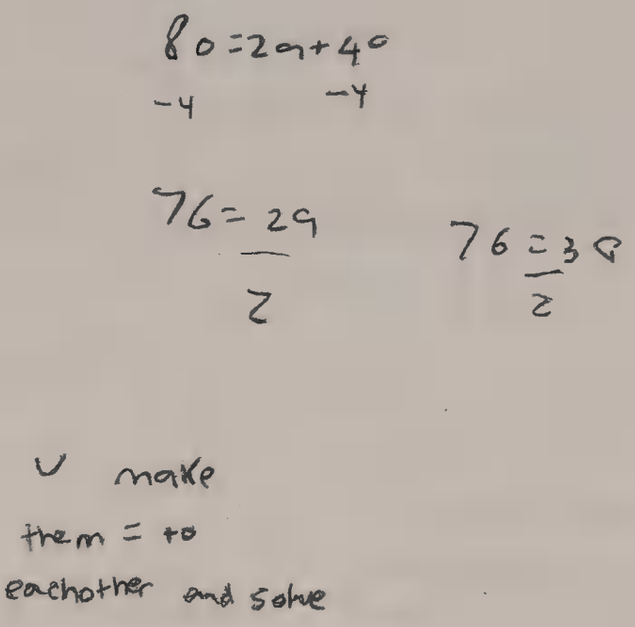

Figure 4. A second student writing sample of category B.

the mathematical sentences or equations. PQR=20 is a complete mathematical sentence, in that "PQR" is the subject, "=" is the linking verb (is equal to), and "20" is the predicate nominative. Unlike a typical sentence, there is no punctuation at the end, after "20." In addition to this mathematical sentence, this student wrote an additional sentence that did not necessarily add an explanation of how to solve the mathematical problem. Rather, it provided a definition to clarify the mathematical sentence. There are no mathematical symbols or algorithms in this second sentence. It consists of only words. These words include terminology specific to the mathematics problem in Figure 2 ("RQS," "PQR," "bisecting") and words that have a mathematical connotation to them ("segment").

Category B—Incorporation of Logograms and Numbers. There were four writing samples in this category. In this category, three students only wrote one sentence, and one student wrote two sentences (see Figure 3).

Figure 3 is a typical example of writing in Category B. m∠PQS = 27° is a complete mathematical sentence. "=" is the linking verb, linking m∠PQS to 27°. In addition, separate from the mathematical sentences, there are scripted longhand sentences. Unlike Category A, in this category, there are numbers and mathematical symbols used as nouns, within the text. The mathematical verbs are written into words ("bisects," "equals," "divides"), and the use of linking verbs (is) and action verbs (make, solve) have mathematical connotations. The numbers and mathematical symbols are used as subjects, objects, or predicate nominatives, within the scripted longhand sentences. They are not part of a mathematical equation. For example, the student wrote

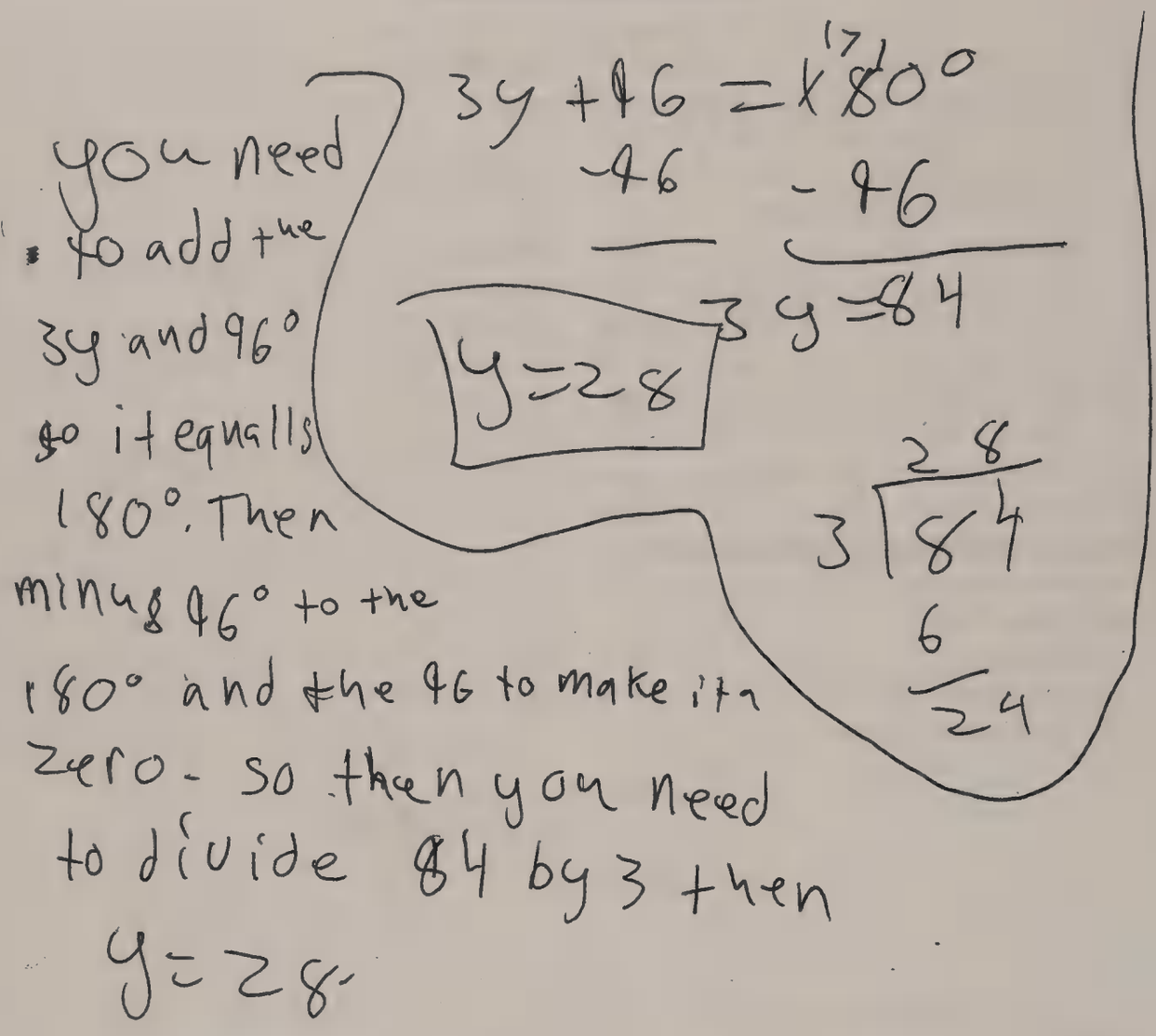

Figure 5. Student writing sample of category C.

"then, m∠PQS is also 27." Here, m∠PQS is the subject, and "27" is the predicate nominative. The meaning of this clause is the same as the equation. The only difference is that the equation has "=" as its linking verb. In the scripted longhand writing, the mathematical notation is used as a form of shorthand. Instead of writing "the measure of the angle PQS," this student wrote m∠PQS. Unlike Category A, the scripted longhand writing is used to define and explain the mathematical process. First, she/he wrote the definition ("when a ray bisects an angle it divides it into 2 =∠ 's"). Then, the second half of the sentence gives an explanation of the process ("since m∠SQR is 27, then m∠PQS is 27").

Similar to Figure 3, this student used "=" at the linking verb, connecting the subject "80" to the compound predicate nominative "$2a + 4°$." In addition, this student used a mathematical symbol ("=") as a gerund, within the text. This mathematical symbol is not part of a mathematical equation. Rather it is used to clarify the mathematical functions that were written previously to it.

In Category B, the students write as if they feel that their English teacher has some comprehension of the mathematics. Here, since the students chose to use the notation as a form of shorthand, instead of writing a complete explanation of the two angles, the students may have made an assumption that their teacher has some understanding of the mathematics. However, similar to Category A, writing in Category B provided an initial definition, before explaining the mathematical process. This format of text is commonly seen in geometry textbooks, where there is a short explanation followed by the mathematical processes (Boyd, Cummins, Malloy, Carter, & Flores, 2005). In both instances, it shows that the writer may have felt that their audience may not have had complete understanding of the mathematics. For the geometry textbook, the writer is the author, and the audience is the students. Category B shows that the student is the writer, and the teacher is the audience.

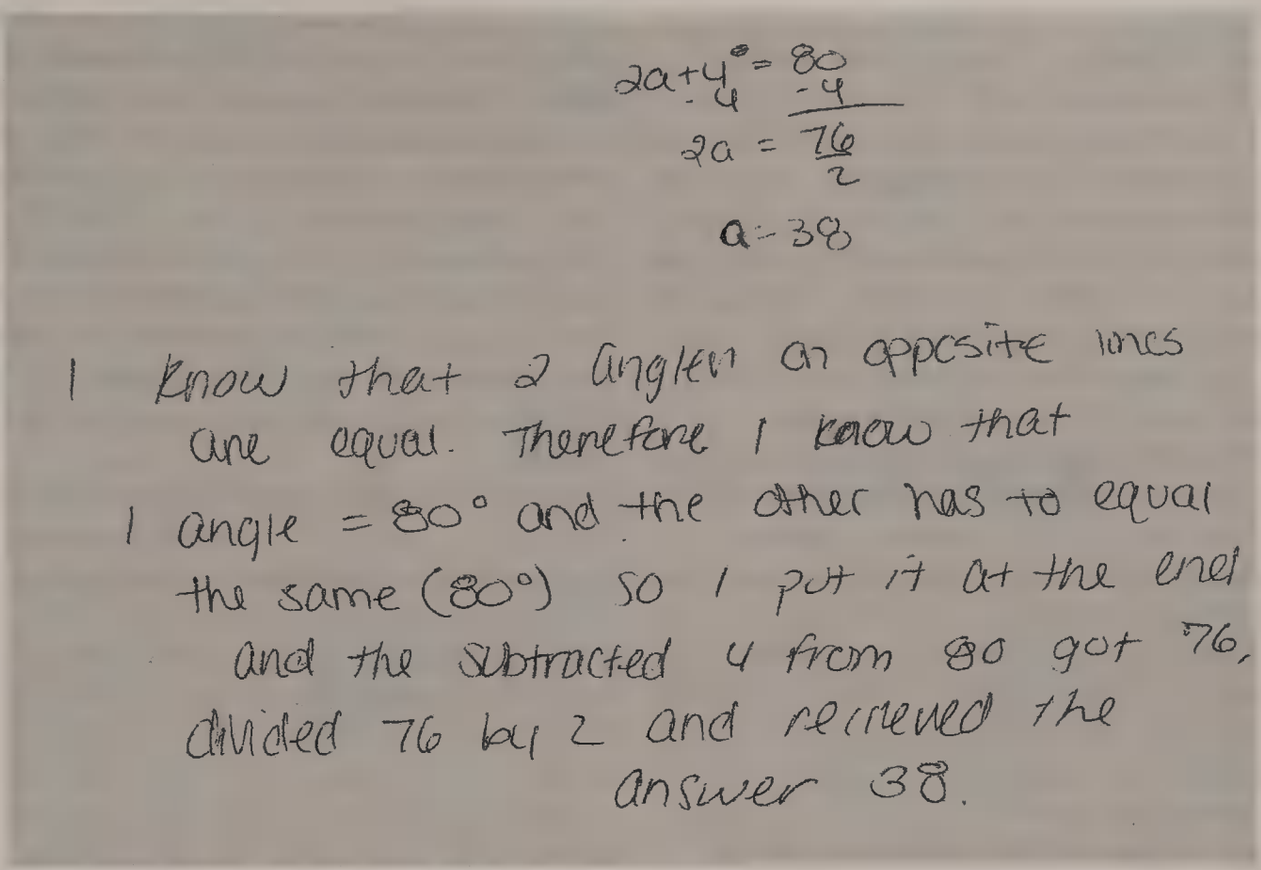
2a+4°=80
-4 -4
2a = 76/2
a=38
I know that 2 angles on opposite lines are equal. Therefore I know that 1 angle = 80° and the other has to equal the same (80°) so I put it at the end and the subtracted 4 from 80 got 76, divided 76 by 2 and received the answer 38.

Figure 6. A second student writing sample of category C.

Table 1
Chart of the Distribution of Writing Samples as Compared to the Students' Teachers

Teacher	Mr. M only	Mr. M and Mr. E	Mr. E only
Numbers and Mathematical Symbols Only	24 samples	11 samples	8 samples
Numbers, Mathematical Symbols, and Scripted Longhand	0 samples	6 samples	9 samples

Category C—Mathematical symbols as verbs. There were 6 writing samples in this category. In Category C, two students only wrote one sentence, one student wrote two sentences, and three students wrote three sentences (see Figure 5).

In this category, while the scripted longhand writing is still a separate entity from the mathematical computations, additional equations, which are taken from the mathematical computations, are incorporated into the written text. These equations are clear clauses that are incorporated into the text. Instead of writing the mathematical process in scripted longhand form, they used equations as a form of shorthand. For example, instead of writing "then the value of y is equal to 28," the student wrote "then $y = 28$," using four mathematical words and symbols instead of nine mathematical words and symbols.

In Figure 6, there are two scripted longhand sentences written: a simple sentence and a long sentence with a series of compound verbs. While the scripted longhand sentences are a separate entity from the equations, mathematical equations are used as a form of shorthand. For instance, this student wrote "1 angle = 80°." At the same time, this student used scripted longhand to describe the mathematical processes that was previously written in the equations, "…subtracted 4 from 80 got 76, divided 76 by 2 and received the answer 38." Numbers are used as a form of shorthand, for this student did not write each number in scripted longhand, even though this student used mathematical verbs within the sentence.

Results Regarding the Nature of Mathematical Writing and Audience

Of the 58 writing samples, 43 writing samples (i.e.

74%) had numbers and mathematical symbols only, in the form of equations. Fifteen writing samples (i.e. 26%) had equations and scripted longhand; these samples had equations on one part of the page and verbal sentences on the other part of the page. There were one to three sentences per writing sample. None of these writing samples contained complete paragraphs. However, all 15 writing samples came from students who completed the writing prompt in English class.

Also, four students had the same mathematics and English teachers. Of these four students, three of them wrote differently for their English teacher, as compared to their mathematics teacher. The writing samples collected from their English teacher contained more scripted longhand words in additional to mathematical equations than the writing samples collected from the mathematics teacher, which only contained mathematical equations. In fact, none of these three students wrote scripted longhand words in the writing samples collected from their mathematics teacher. They only wrote mathematical equations and symbols in response to prompts assigned by their mathematics teacher.

Writing samples collected in the mathematics classes reflected the writing presented by the mathematics teacher. The mathematics teacher used numbers, logograms, and pictograms in his routine teaching. Also, instead of using traditional scripted longhand sentences, he used equations. The writing samples collected from the students in the mathematics class reflected this style of writing. All of Mr. M.'s students wrote numbers, logograms, and pictograms in the form of equations in their mathematical writing. They did not use scripted longhand in any of their mathematical writing. All students followed the pattern.

Writing samples collected in the English class reflected the writing that was presented by the English teacher. Mr. E. used scripted longhand in his routine instruction. When he gave a worksheet or writing prompts, he used words and complete sentences. The student writing reflected this presentation. There were nine writing samples that consisted of scripted longhand and eight writing samples that consisted of only numbers, logograms, and pictograms, in the form of equations. The writing samples that contained scripted longhand were reflective of the writing, which was presented in class. These writing samples contained complete sentences that either defined or explained the mathematics that the students were asked to solve. Three students followed the pattern, and one student did not.

Writing prompts that were written as a friend were given in both the mathematics classes and the English classes. Then, writing samples did not reflect the style of writing in the prompt. Instead of using slang and other idiomatic expressions, these writing samples used more formal language, and they reflected the writing that was presented in the mathematics and English classes. There was no difference between these writing samples and the writing samples from the prompts that were written in the style of the teachers. The students still interpreted the assignments as coming from the teachers.

Four students in this study received instruction from both Mr. M. and Mr. E., and they received writing prompts from both teachers as part of their routine instruction. There were a total of 17 writing samples from this sample of students. In this population, three of the four students changed their mathematical writing according to their audience. These three students produced 12 writing samples. Within these 12 writing samples, six were collected in the mathematics class, and six were collected in the English class. The six writing samples that were collected in the mathematics class were reflective of the writing that was presented by Mr. M. In the English class, six writing samples were collected, and they contained scripted longhand in addition to equations. The scripted longhand contained complete sentences, reflecting the style similar to what the students were taught in their English class.

This group, who had both Mr. E. and Mr. M. as teachers, showed that the students did change their mathematical writing as their audience changed. They wrote only equations to Mr. M., but when they wrote to Mr. E., there were scripted longhand sentences in addition to the equations. Scripted longhand sentences were the expectation in Mr. E.'s class, and they gave it to him.

Discussion

As stated earlier, the writing samples were divided into two categories: writing that consisted of only equations and writing that consisted of equations and scripted words. Between these two major categories, three types of mathematical writing emerged. I call them: Separated Writing, Code Switching, and Multiliterate Hybridity. Separated Writing consists of only numbers, logograms, and other mathematical symbols, in the form of equations. In this case, the student uses only one kind of mathematical writing. Code Switching consists of enumeration and scripted longhand, on

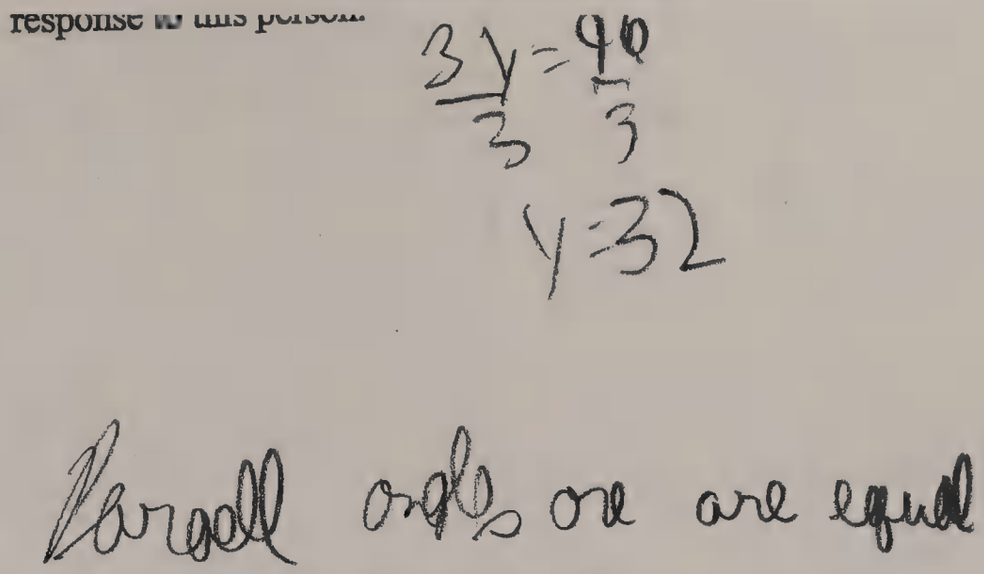

Figure 7. Chart of the distribution of writing samples as compared to the students' teachers.

the same page. However, these two kinds of writing are separate entities on the page. The third type of writing is Multiliterate Hybridity. In Multiliterate Hybridity, the students' mathematical writing contains both enumeration and scripted longhand. However, these two kinds of mathematical writing are intertwined in order to explain a single mathematical process.

First Type of Writing—Separated Writing

Separated Writing consists of only numbers, logograms, and other mathematical symbols, in the form of an equation. It uses one form of mathematical language to explain the problem solving processes. In this case, the students only used equations, which could be seen as monolingual, using only one kind of mathematical language: numbers, logograms, and pictograms. These mathematical equations can be clear in its explanation, provided that the reader is able to understand this language. For example, when a student wrote $2y + 4 = 180$, this equation is considered Separated Writing. The student only used one kind of mathematical language, in this case enumeration and nominalization, in his writing. In addition, this student did not use any scripted longhand in his writing. Of those obtained from the mathematics class, all but one writing sample had Separated Writing.

The reason why Separated Writing was primarily seen in the mathematics class. The first possible reason is that the students were writing in a language that was expected of them. Mr. M. did not use much scripted longhand in his teaching, and the scripted longhand that he did use was specifically mathematical in nature. For example, when he wrote on the chalkboard, he wrote: "if," "then," "also," and "from." Even when he wrote the homework assignment on the chalkboard, at the end of class, he wrote a series of numbers that signified the problems to be solved in their textbook. He did not write any scripted longhand explanatory information about the methodology or details about the individual homework problems. As a result, Mr. M. only exposed to the students the use of numbers, logograms and pictograms. With Separated Writing, it shows that all of the students followed Mr. M's example.

Second Type of Writing—Code Switching

I coined the term Code Switching to this second type of writing, because students used two different kinds of mathematical language, scripted words and equations on the same page. This kind of writing can be seen in figure 7.

In this example, there are three sentences. The first two sentences are numerical equations, and the third sentence is written in scripted longhand. The scripted longhand sentence ("Paraell [sic] angles one are equal") is a separate entity from the equations ("$y = 32$"). Intermediate writing gives the reader some idea that the student understands the mathematical concepts involved in solving the problem. Since the student is able to communicate either a definition or explanation of the mathematical concepts that are expressed in the problem, it is clear that this student is more knowledgeable in the mathematical processes (Goldsby & Cozza, 2002).

Code Switching uses numbers and mathematical symbols as nouns, within the written text. The student uses subject specific lexicon to explain the mathematical process. Mathematical lexicon consists of numbers, mathematical symbols, and mathematical vocabulary and definitions. Numbers and mathematical symbols are used as nouns, as a form of shorthand. For

example, in figure 3, instead of writing "two," the student wrote "2." At the same time, the student uses scripted longhand, writing out the mathematical verbs. Also, in these cases, the writing is a separate entity from the simple mathematical text. For example, in figure 4, one student wrote: $80° = 2a + 4$, and solved this equation to find that $a = 38°$. Below this enumeration, he also wrote, "U make them = to eachother [sic] and solve". In the latter sentence, the "=" is used as a gerund, or a noun. It is not used to designate "is equal to" as in the Separated Writing. Instead, it is used to clarify a mathematical idea, which was expressed in the equation.

Code Switching is commonly seen in journals and learning log entries. When students try to convey their metacognitive and affective processes, they may explicate their emotions and thoughts in scripted longhand. The mathematics, in question, is separate from the actual scripted longhand text (Borasi & Rose, 1989). This kind of mathematical writing uses numbers and mathematical symbols as nouns, subjects and objects in the text. Equations are not necessarily used to designate complete sentences. In regards to language, this kind of writing would be similar to a student, who is learning Spanish, using Spanish words within an English context. In both cases, the reader has the impression that the student has some grasp of the language, but that same student may not be fluent enough to use both languages interchangeably. Rather, this student may only be able to use isolated words and ideas of the new language and incorporate what she/he knows within the current language. In Code Switching, the new language is mathematical language and the current language is English.

Third Type of Writing—Multiliterate Hybridity

Multiliterate Hybridity is similar to Code Switching, because both kinds of writing consist of scripted longhand and enumeration. However, with Multiliterate Hybridity, the scripted longhand and enumeration are entwined, in a sense, to explain the mathematical processes. Mathematical equations are incorporated and used as individual sentences as part of the explanatory process. Referring to Figure 5, it is an example of Multiliterate Hybridity. As seen in this example, the student solved the equation numerically, but off to the left side, this same student used scripted longhand to add an explanation to his use of equations. While the student's writing is not grammatically correct, he did use mathematical symbols as predicates (y=28°), and he incorporated numerical text and language in his explanation (Then minus 96 to the 180 and the 96 to make it a zero [sic]).

The ability to incorporate scripted longhand and mathematical language is the most multiliterate form of mathematical writing, because it shows complete incorporation of two languages (mathematical language and English) in a single coherent form. With Multiliterate Hybridity, it is clear that the student has a clear grasp of the mathematical concept. In the first example, the student understood that vertical angles were congruent. Once that designation was made, then he solved the problem, finding the value of the variable. In the second example, this student did not clearly state that the sum of the two angles equaled 180 degrees, because they were corresponding angles on opposite sides of parallel lines, which were cut by a transversal. Instead, he showed, in written form, that it was necessary to equate the angles to 180 degrees, before the problem could be solved. The only mention of parallel lines was in the diagram and the problem itself. However, this student took this idea and applied it to his solution.

This Multiliterate Hybridity is seen in professional mathematics journal articles. For example, mathematicians manipulate language to clarify and explain their mathematical process to the mathematical Discourse community (Burton & Morgan, 2000). In a crude way, the students act similarly. In this case, the 3 of the 13 students manipulated language within the mathematical Discourse, incorporating both scripted longhand and mathematical equations to clearly explain a mathematical process. Multiliterate Hybridity also shows how students are engaged in the meaning-making process of mathematics. For this process to be effective, students took what was interpreted (in this case the mathematics) and incorporated that information into their own lexicon. Bahktin (1935/1981) stated that this interpreting process takes place within the specific socio-cultural context. This juxtaposition of language shows duality, the ability to flit back and forth between languages, with relative ease and coherency. Also, these students used mathematical concepts in mathematical situations. For example, in Figure 14, the student used non-mathematical language to show mathematical concepts. For example, this student wrote, ". . . to make it a zero" to mean, "equals to." According to Pugalee (2001), this manipulation of texts is a sign of mathematical literacy.

Once again, if a student is learning Spanish, she/he is becoming more literate in the language. If that per-

son is able to blend Spanish and English sentences in text, in a coherent manner, then it is clear that the student has some command of both languages. While this interspersing of language does not necessarily show fluency, it does show that she/he is able to appropriately manipulate the languages to some degree. The same can be seen in the Multiliterate Hybridity. The student is able to incorporate both kinds of mathematical language, equations and scripted longhand, into a coherent explanation. While it may not be clear that the student is truly fluent in mathematical language, what is clear is that she/he has some command of it and is able to use them accordingly.

Implications for Mathematics Education

This study showed that mathematical writing existed in scripted longhand and mathematical symbols, logograms, and numbers. Neither form of mathematical writing was seen as better or more important. Rather both forms of mathematical writing were necessary to convey complete meaning in her/his mathematical writing.

In mathematical class, the students wrote mathematically through the use of equations. This kind of mathematical writing was reflective of what the students' mathematics teacher presented during his routine classroom instruction, since he used few scripted words and mostly used numbers, logograms, and pictograms in his instruction. When the students wrote mathematically in English class, a different kind of mathematical writing emerged. Here, in addition to equations, students used scripted longhand, words and scripted sentences, to explain their mathematical ideas. Also, these students used numbers, logograms, and pictograms as nouns and verbs, embedding these mathematical symbols into the scripted words. Students in the English class were exposed to scripted longhand during their routine instruction, and all of their instructional materials contained this kind of writing. Thus, the students' mathematical writing reflected the English teacher's writing.

This study showed that students do attend to audience. If the mathematics audience presents only the use of numbers, mathematical symbols, and logograms, then the students will follow suit, because they think that emulating the teacher will foster a better grade for them. If scripted longhand is taught only in English classes, then writing in the different disciplines will not get developed. Three modes of mathematical writing emerged in this study: mathematical writing that consists of mathematical symbols and numbers in the form of equations only, mathematical writing that consists of words only, and mathematical writing that is a hybridization of both words and mathematical symbols and numbers.

In the learning of mathematics, students need to learn how to manipulate the various modes of communication. These modes include mathematical signs, mathematical symbols, and subject specific vocabulary. If students use only one mode of mathematical communication, either scripted words or equations only, they are able to convey mathematical meaning, but that meaning may be limited. By using the full range of communication tools, students show that they understand and can manipulate the full range of mathematical language. When students intertwine equations and scripted longhand into complete sentences within one document, a more comprehensive meaning emerges. Students not only understand the basis of the mathematics, but these same students understand how mathematical language is manipulated to convey their mathematical meanings.

National Council of Teachers of Mathematics issued six principles for school mathematics and ten standards that students should meet, at each grade level (NCTM, 2000). One of the standards is Communication. In this standard, NCTM stated that students in grades 9-12 should "organize and consolidate their mathematical thinking through communication; communicate their mathematical thinking coherently and clearly to peers, teachers, and others; analyze and evaluate the mathematical thinking and strategies of others; and use the language of mathematics to express mathematical ideas precisely (NCTM, p. 348). Current reform efforts focus on these communication standards, but the focus is primarily on the students. With this study, I wanted to show that teachers are also responsible for the way their students communicate mathematically. Teachers may tell their students to use scripted longhand in a writing assignment, but if teachers do not model and regularly incorporate scripted longhand in their routine daily instruction, then the students may not follow suit.

If mathematics teachers want their students to use a full range of mathematical writing when explaining mathematics problems and processes, it is necessary for these teachers to incorporate all of the modes of mathematical writing in their routine daily instruction. For many secondary level students, their mathematics textbook consists of numerical and symbolic writing. As a result, students learn to read and interpret a certain

kind of mathematical writing. In addition to reading instruction, mathematics teachers need to teach their students how to properly write mathematically, using language and discourse that would be accepted in the mathematical community. This language is more than a series of mathematical signs, symbols, and vocabulary. It is the incorporation of the mathematical language into their existing knowledge, showing multiliterate hybridity. Mathematics teachers need to actively model and instruct their lessons using this incorporation of language if they want their students to learn and use the full range of mathematical language in their writing.

In the classroom, the teacher is an influential figure. Students perceive what these expectations are, and they, whether is consciously or not, will try to meet those expectations. This study showed that teacher presentation influenced the writing of the students. From the presentation, students attended to their audiences, adapting their writing as they saw fit. This study links the ideas of teacher presentation and audience theory, showing that they are dependent on one another. It adds strength to the current research on teacher presentation, showing one way of how students perceive the presentations.

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Fantasy Baseball and Mathematics: A Resource Guide for Teachers and Parents

Author: Dan Flockhart

Jossey-Bass: An Imprint of Wiley
989 Market Street
San Francisco, CA 94103-1741

2007; 203 pages
Paperback; $24.95

Reviewer: Carl Miller
Northern Kentucky University
Highland Heights, KY 41099

Fantasy Baseball and Mathematics: A Resource Guide for Teachers and Parents is a potential goldmine for instruction. As a resource tool, this may be used by a teacher in the classroom, or even by a parent during the summer, to guide young learners. There are multiple examples given which clearly explain the overall process, and the numerous handouts included make the workload very minimal. Overall, this a tremendous resource for playing fantasy baseball.

The first chapter begins with an overview of the game. Initially, there are two options given for choosing teams. The first option includes a salary cap restriction, which can be used to stimulate discussion about optimum strategy for the "best" fantasy team as opposed to selecting "best" individual players. Note that a fantasy team is virtually always comprised of players from different major league baseball (MLB) teams. The second option allows the selection of one of the actual MLB teams each week. Of course the instructor can add complexity by allowing trades or player replacements for injuries.

The next step involves reading the box score from a newspaper or electronic source. Many people will check a web resource such as ESPN's website, MLB's website, or a local news source's website to locate the box scores. Details are clearly given on how to read the information for both the position players (non-pitchers) and for the pitchers. These daily results will then be used to tally points for each student's team. Depending on the scoring system used, this tally may be very quick, around 15 minutes, or considerably longer for more complicated systems. Also, a teacher using this while teaching various topics may choose to use a different system for scoring each week (daily would likely be too cumbersome). This would add flexibility and keep the scoring fresh (i.e.: not the same repetitive system for multiple weeks).

Perhaps one of the strongest things about the book now appears. Page 17 begins the different scoring systems. These are broken down into Integers (1 – 3), Fractions (4 – 41), Decimals (42 – 71), Fractions and Decimals combined (72 – 97), Fractions with Positive Exponents (98 – 105), Fractions with Negative Exponents (106 – 113), Decimals with Positive Exponents (114 – 121), Decimals with Negative Exponents (122 – 129), Integers with Positive Exponents (130 – 139), Integers with Negative Exponents (140 – 149), Roots (150 – 157), Factorials and Summations (158 – 161), and "everything mixed together" (162 – 165). So teachers and parents do not have to develop their own scoring systems, although they are welcome to do so. There are scoring systems which allow very simple calculations (i.e.: Integers) for elementary level children or just to get used to scoring, all the way to the very complex mixing of roots, fractions, and exponents all mingled together, which could challenge high school students. The only drawback that might be present is that there is so much available, some people might feel overwhelmed at the options. But this could be used to teach about organization and attention to detail. So if students are told to use the scoring system numbered 147, and they do not, a discussion on lack of attention to detail can be held. Although it is not directly a math topic, this organizational ability is still extremely necessary to "do the math". So not only is a math lesson being taught, but also a life lesson.

Chapter 2 then discusses the handouts in detail. Examples are given as to how to fill out each sheet, from initially selecting a team, to reading box scores to get a player's results, to tallying points for the current scoring system, and tracking point totals across time. The next section then discusses using graphical displays to represent information. Circle graphs, bar charts, and multiple line graphs are represented, but teachers can

always modify these to include other displays they may be discussing.

Chapter 4 begins to use sports data within common mathematics topics. From things like equivalent fractions, to percentage changes in prices, to unit conversions, examples using baseball and other sports data are given. Chapter 5 then gives matching quizzes over the same material discussed in chapter 4. This allows discussion of topics and practice with the worksheets in chapter 4 to be assessed easily by selecting the matching quiz from the following chapter. The remaining two chapters include an optional pretest/posttest in chapter 6, with answer keys to previous materials (from chapters 4 through 6) in chapter 7.

Overall this is a great resource for sports-interested students. This would be a great spring unit in a school, or perhaps a fun summer activity for the kids who are not in school for the summer but need to be actively using their math skills to keep them up to par. All of the needed materials are present to make the workload on the instructor minimal, although it would take a bit of effort to get things started. Once it is going, the weekly tallying of points and tracking of results should be rather minimal for the instructor (the student will spend time reading box scores and calculating points, but if done daily, this should be less than 15 minutes). This is a fun way for sports fans to work on their math skills while keeping up with baseball.

Assessment in Science: Practical Experiences and Education Research

Editors: Maureen McMahon, Patricia Simmons, Randy Sommers, Diane DeBates, & Frank Crawley

National Science Teachers Association Press
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Arlington, VA 22201

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NSTA Member Price: $20.76
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Reviewer: Lloyd H. Barrow
University of Missouri
Columbia, MO 65203

This 18 chapter monograph resulted from a joint group from National Science Teachers Association and National Association for Research in Science Teaching. This resource was designed for a wide audience of teachers of science, science education researchers and teachers as researchers and focused upon the best assessment practices of K-16 science.

Each chapter is independent invited submissions and that addressed broad areas of assessment. The call for submission requested new assessment strategies, suggestions for challenges in assessment, evidence of student understanding, and practical implications. This resource is to extend National Research Council's *Classroom Assessment and the National Science Education Standards* (2001). The first 13 chapters focus upon science assessment research which emphasizes practical applications for classroom teachers. The last 5 chapters have a role for teacher-as-researcher (action research). A variety of perspectives includes theoretical background to practical successful assessment strategies.

Each chapter has an abstract included in the table of concepts. Editors have included brief author's orientation toward assessment organized by chapters in their introductory chapter. Each chapter is independent with separate bibliographical entries and resources recommended (print and electronic). Each of the chapters and original manuscripts, some of which are based upon grant founded projects. An extensive index is provided.

This paperback is a through resource for any science educator with an interest/responsibility with assessment. Since each chapter is independent, readers can choose specific chapter(s) to read on specific aspects associated with assessment. Then readers can consult index to find related uses. The reviewer would have liked the editors to have provided a synthesis chapter to conclude this resource.

PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to: Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel; or fax to:972-86-477-648. Questions concerning proposals and/or solutions can be emailed to: eisenbt@013.net. Solutions to previously stated problems can be seen at: ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before April 15, 2009

5050: *Proposed by Kenneth Korbin, New York, NY.*

Given $\triangle ABC$ with integer-length sides, and with $\angle A=120°$, and with $(a, b, c)=1$.

Find the lengths of b and c if side $a = 19$, and if $a = 19^2$, and if $a = 19^4$.

5051: *Proposed by Kenneth Korbin, New York, NY.*

Find four pairs of positive integers (x, y) such that $\dfrac{(x-y)^2}{x+y}=8$ with $x<y$.

Find a formula for obtaining additional pairs of these integers.

5052: *Proposed by Juan-Bosco Romero Márquez, Valladolid, Spain.*

If $a \geq 0$, evaluate:

$$\int_0^{+\infty} arctg\frac{2a(1+ax)}{x^2(1+a^2)+2ax+1-a^2}\frac{dx}{1+x^2}.$$

5053: *Proposed by Panagiote Ligouras, Alberobello, Italy.*

Let a, b and c be the sides, r the in-radius, and R the circumradius of triangle ABC. Prove or disprove that

$$\frac{(a+b-c)(b+c-a)(c+a-b)}{a+b+c}\leq 2rR.$$

5054: *Proposed by José Luis Díaz-Barrero, Barcelona, Spain.*

Let x, y, z be positive numbers such that $xyz = 1$. Prove that

$$\frac{x^3}{x^2+xy+y^2}+\frac{y^3}{y^2+yz+z^2}+\frac{z^3}{z^2+zx+z^2}\geq 1.$$

5055: *Proposed by Ovidiu Furdui, Toledo, OH.*

Let α be a positive real number. Find the limit

$$\lim_{n\to\infty}\sum_{k=1}^{n}\frac{1}{n+k^{\alpha}}$$

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Time to review: 6-7 months
Reviewers' comments: Yes
Invited articles: 5% or less

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Science, mathematics, and connections between science and mathematics for grades K-graduate and teacher education, especially science and mathematics articles that deal with assessment, attitudes, beliefs, curriculum, equity, research, translating research into practice, learning theory, alterative conceptions, philosophy and history of science, sociocultural issues, special populations, technology, nontraditional forms of instruction, and science/technology/society.

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Source of publication guidelines: Publication Manual of the American Psychological Association, 5th Edition.

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Manuscript preparation:

All manuscripts must be prepared according to the 5th Edition of the Publication Manual of the American Psychological Association, typed double-spaced using a 12-point or larger font, and printed on 8 1/2- by 11-inch paper. Manuscripts should be limited to 25 pages, excluding figures, tables, and appendices. **Submissions that are not APA style or exceed the length limitation will be returned.**

Manuscript Submission: All manuscripts must be submitted electronically at the web site ssmj.tamu.edu. The following components are required:

1. An abstract not to exceed 200 words on a separate page
2. To maintain anonymity of the author(s), author(s) citing their own work should cite as follows:
   In text: Author (1999) found...
   On reference list: Author (2005). Journal Title. (Do not include title of article or volume and page #)
3. Graphics submitted as publication-ready copy on white background with black type. Each table or figure should be on a separate page at the end of the manuscript, with a note within the ms where the graphic should be placed. Use no smaller than 8-point font for text on figures; use no smaller than 11-point font for tables. Figures and tables should be no wider than 6.75 inches.

Manuscripts submitted for review will be evaluated on the following:

All manuscripts:

Relevence, timeliness, and significance
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Literature review
Theoretical/literature-based framework

Research manuscripts only:

Design and methodology
Analyses of data
Conclusions based on results
Results related to professional practice and literature
Enough information to enable replication (quantitative)

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IN THIS issue

Research Articles

Effect of Similarity-Based Guided Discovery Learning on Conceptual Performance

Pierre-A Mandrin, Daniel Preckel

Analogies are known to foster concept learning, whereas discovery learning is effective for transfer. By combining discovery learning and analogies or similarities of concepts, attractive new arrangements emerge, but do they maintain both concept and transfer effects? Unfortunately, there is a lack of data confirming such combined effectiveness. This experimental study involving 280 young students in the domain of physics showed that adequately structured similarities between mechanics and geometry improves conceptual performance (perception of functional relations) by as much for discovery learning as for conventional teaching texts with questions. Adequate structures were provided following Glynn's teaching with analogy model. The learning form had no significant impact on concept performance. The effect of similarity increased when the level of difficulty of the treatment was raised. These results were found using a 2□2-factorial design. A qualitative questionnaire provided individual information about the usefulness of similarities and about learning strategies of the participants.

Mix It Up: Teachers' Beliefs on Mixing Mathematics and Science

Joey Offer, Selina Vasquez Mireles

This paper defines correlation, describes the Mix It Up program, discusses the teachers' beliefs about the value of correlating mathematics and science prior to program participation, and identifies problems teachers associated with correlation before and during the program. Teachers' beliefs about the value of correlation and about the problems associated with correlation are based on results from both quantitative and qualitative methods used to evaluate the program. Results indicate that teachers believe correlating mathematics and science strengthens students' content knowledge in mathematics and science, bridges the gap between mathematics and science, enhances motivation, and increases students' flexibility in problem solving. Additionally, the areas identified by teachers to be most problematic were time, planning for instruction as a team, and exposure to correlation in the past. The most important finding from the program evaluation indicates that although teachers did not identify content knowledge weaknesses before participating in the program, they did recognize gaps in their own content knowledge during program participation, and more importantly they made connections among these gaps, classroom instruction, and their own students' performance in mathematics and science.

Mathematics and Science Integration: Models and Characterizations

Kevin Stinson, Shelly Sheats Harkness, Helen Meyer, James Stallworth

The squeeze on instructional time and other factors increasingly leads educators to consider mathematics and science integration in an effort to be more efficient and effective. Unfortunately, the need for common understandings for what it means to integrate these disciplines, as well as the need for improving disciplinary knowledge, appears to continue to be significant obstacles to an integrated approach to instruction. In this study we report the results of a survey containing six instructional scenarios administered to thirty-three middle grades science and math teachers. Analysis of teacher responses revealed that while teachers applied similar criteria in their reasoning, they did not possess common characterizations for integration. Furthermore, analysis suggested that content knowledge serves as a barrier to recognizing integrated examples. Implications for professional development planners include the need to develop and provide teachers with constructs and parameters for what constitutes mathematics and science integration. Continued emphasis on improving teacher content knowledge in both mathematics and science is also a prerequisite to enabling teachers to integrate content.

Scientists' Perspective on Introducing Authentic Inquiry to High School Teachers During an Intensive Three-Week Summer Professional Development Experience

Laura E. Ruebush, Ethan L. Grossman, Stephen A. Miller, Simon W. North, Jane F. Schielack, Eric E. Simanek

The Information Technology in Science (ITS) Center for Teaching and Learning was a National Science

Foundation funded program to provide high-quality professional development for 7-12th grade science teachers. The subgroup on which this paper focuses was immersed in an innovative approach to understanding chemistry of the environment. The group was comprised of 10 high school science teachers representative of science classes taught at all grade levels (9-12th). A team of four university professors led the group. The professors developed inquiry modules and communicated some of the intricacies of their research for adaptation to the participants' classrooms. This paper communicates the successful implementation and lessons learned by scientists during the course of an inquiry-based curriculum during summer 2005. The process and pace at which the material was covered, qualitative information about the attitudes of the participants towards the curriculum, and implications for professional development from the point of view of the science team leaders will be discussed. Analysis of time spent with participants revealed the progression and type of activities chosen for the professional development experience were effective. Results from informal participant interviews revealed they were most comfortable in incorporating inquiry into their classrooms after having been immersed in it themselves.

Short Report

Undergraduate Engineering Majors' Beliefs About Mathematics

Zaur Berkaliev, Peter Kloosterman

This study examined the mathematics beliefs of college students in 10 undergraduate mathematics classes at a large engineering school in the Midwest. The beliefs of 254 engineering majors were measured by the Indiana Mathematics Belief Scales and compared to the beliefs of elementary education majors and remedial college mathematics students obtained from earlier studies using the same instrument. The results were interpreted in terms of the students' daily attitudes towards their mathematics classes and corresponding academic and demographic parameters. The study showed that in many respects, the beliefs of the engineering majors were not that different from the other populations. The correlations among beliefs for the engineering group tended to be higher although there were relatively few significant correlations between belief and background variables. Attitude data were collected across a full semester for the engineering majors. The relatively modest day-to-day variation in those attitudes suggests that they are based on deeply seated beliefs.

Effect of Similarity-Based Guided Discovery Learning on Conceptual Performance

Pierre-A Mandrin
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Analogies are known to foster concept learning, whereas discovery learning is effective for transfer. By combining discovery learning and analogies or similarities of concepts, attractive new arrangements emerge, but do they maintain both concept and transfer effects? Unfortunately, there is a lack of data confirming such combined effectiveness. This experimental study involving 280 young students in the domain of physics showed that adequately structured similarities between mechanics and geometry improves conceptual performance (perception of functional relations) by as much for discovery learning as for conventional teaching texts with questions. Adequate structures were provided following Glynn's teaching with analogy model. The learning form had no significant impact on concept performance. The effect of similarity increased when the level of difficulty of the treatment was raised. These results were found using a 2×2-factorial design. A qualitative questionnaire provided individual information about the usefulness of similarities and about learning strategies of the participants.

One of the major concerns in science education is how to foster thinking with similarities (or analogies), in order to improve the understanding of general science concepts. Indeed, quite a lot of concepts of usual curricula in secondary education yield similar features. The first author has started to integrate similarity of concepts in various approaches of guided discovery learning during school programs. He aimed at a facilitated transfer of concepts by similarity. The still unresolved question about the effectiveness of similarity-based discovery learning was the starting point of this study.

Discovery Learning

Various definitions of the term *discovery learning* exist within instructional research. As Anderson (2002) points out, the term of *inquiry teaching* is often employed in US to design guided discovery learning as well as open inquiry learning. However, the conception used in this study is much more restrictive. Therefore, it shall first be delimited from other conceptions. A taxonomy of laboratory instruction styles has been proposed by Domin (1999) and may additionally prove helpful for more general purposes.

Guided Discovery Learning (or *discovery learning*) denotes, according to Domin's taxonomy, an instruction style by which the learners are led to discover a predetermined outcome. The predetermined goal usually consists of finding some general principle. The learners commonly develop this general principle by studying specific situations (that is, by induction).

Open Inquiry Learning or *inquiry learning*, sometimes also called *open discovery learning* (e.g. Mayer, 2004) is described in detail by Hameyer (1999). The learners explore a new field in order to acquire a better understanding in this field. However, the teacher has not determined in advance any knowledge to be acquired (e.g., Domin, 1999). The students will rather determine by themselves, which question to investigate and how to proceed. This process is usually inductive.

The first conception of guided discovery learning appeared to be particularly suitable for use in the experimental design of this study. Thus, this type of discovery learning was focused on.

Learning aids are usually included and may be offered in various amounts. In the physics course, for example, if students are to discover the concept of heat flow, the teacher may distribute written information showing useful formal or graphical representations. By performing experiments, the students may discover, for example, that metal rods are better thermal conductors than wooden sticks. The instruction notes describe how the students should proceed and which experimental data they should collect. After completion of the experiments, the students should make conclusions on the properties of thermal conductivity.

Output studies in the past show, in average, an improvement of transfer effects when using guided discovery or inquiry learning rather than direct teaching, such as lectures, for instance. Mayer (2004) briefly summarizes the main findings. Positive effects in respect to school performance have been confirmed by meta-analyses, with a mean effect size of 0.4 or a corresponding correlation of $r = .2$ (Anderson, 2002; Fraser, Walberg, Welch, & Hattie, 1987; Neber, 1981). An effect has also been reported in conjunction with

computer simulations (de Jong & van Joolingen, 1998). The meta-analyses report that there are several moderating factors influencing the effect of discovery or inquiry learning, for example *guidance* and *explicit vs. implicit approach*. Often, successful learning is only made possible by appropriate and sometimes detailed guiding hints (Hameyer, 1999; Mayer, 2004). For example, the teacher instructs the students to examine the precise shape of an experimentally obtained graph of the thermal conductivity of copper. Moreover, inquiry oriented instruction should always precisely foster those competencies which match the immediate goal related to the desired transfer effect (Khishfe & Abd-El-Khalick, 2002). The students shall understand basic general principles, for example of thermal conductivity. The students shall then be able to explain, for example, why a metal plate is felt as being colder than a wooden plate. According to the findings of Khishfe and Abd-El-Khalick, a transfer effect is to be expected if the students themselves discover this general principle and explicitly formulate this principle (explicit-reflective discovery learning). Likewise, the students in the paleontology course shall raise a hypothesis on fossils, - about what a given living being may have looked like. The general principle resides in to what extent scientists are able to reconstruct properties of extinguished living beings and to what extent they are not.

In contrast to the explicit-reflective learning mentioned above, implicit learning occurs if transfer goals are not explicitly referenced (Khishfe & Abd-El-Khalick, 2002). In the last example of paleontology, no emphasis would be made on the reconstruction process of extinguished living beings. Implicit learning as such is usually employed, but may hardly allow the intended transfer goals to be reached.

Although open inquiry learning differs somewhat from guided discovery learning, transfer goals may be applied in both cases.

Analogies and Similarities

According to the definition of Duit (1991) and Duit and Glynn (1995), an "analogy" denotes "similarities between two domains with respect to specific properties" (Duit & Glynn, p. 44). Similarly, Gentner (1989, p. 201) describes an analogy as a "mapping of knowledge from one domain (the base) into another (the target)", thus yielding "relational commonalties" between these domains. One frequently wishes to explain some new concept (target) by referring to a concept already known or understood (base or analog). Thus one considers an analogy relation between the analog and the target.

Example: There is an analogy between an electrical circuit and a water circuit. The electrical circuit is usually introduced as a target (new concept), and the water circuit is used as an analog.

Furthermore, similarities of concepts may link together different contexts or school subjects. In this way, geometry and physics concepts may show many corresponding features. However, students may not fully realize these correspondences by themselves, especially if these concepts are taught by different teachers.

Examples: There is a similarity between the geometric concept of similar triangles (used as an "analog") and the physical behavior of a bicycle on the inclined plane (used as a "target"). Or: The geometric concept of equal surface for rectangles shows similar features as the concept of equal torque for levers. These examples are further considered in the course of this article.

As could be shown in experimental studies, the use of analogies can foster the understanding of concepts. Performance in problem solving and comprehension tests can be improved, and experimental data exist for many different learning conditions. Mayer (1989) summarizes 20 studies; Hammond, Seifert, and Gray (1991) focus on analogical transfer; McVey (1993) combines analogies with meta-cognition; Schwartz (1993) treats symbolic visualizations; Newton and Newton (1995) report on children's understanding; Lin, Shiau, and Lawrenz (1996) use pictorial analogies; Markmann and Gentner (1997) relate analogies with memory effects; Loewenstein, Thompson, and Gentner (1999) deal with multiple analogies; Antonietti (2001) treats and investigates basic learning mechanisms systematically. Several studies yield an effect of more than one standard deviation on performance. However, the use of analogies or similarities also may prove detrimental in certain cases. The learners may develop misconceptions (Duit, Roth, Komorek, & Wilbers, 2001). For example, the above-mentioned analogy between the electrical circuit and the water circuit may give rise to the impression that an electric conductor could be "emptied" like a water pipe. Or in the example of the inclined plane, learners may mistake forces for lengths (such an example is reported in this study). Such misconceptions may lead to a reduced learning performance. Klauer (1991) systematically demonstrates problems which may arise when procedural support is lacking in the education of thinking with analogies.

Without the explicit approach of an analogy, the analogy learning may fail (Brown & Clement, 1989). Therefore, analogy learning generally requires a high level of guidance and learning hints.

Duit (1991) describes how situations of possible misconceptions during instruction with analogies may be confronted, namely by using the following two structuring techniques: "Teaching-with-analogy"-model or TWA-model (Glynn, 1989), and if necessary "Bridging Analogy" (Brown & Clement, 1989; Clement, 1993).

The TWA-model comprises the following steps:

1. The target concept has to be introduced first (e.g. electrical circuit).
2. The learners are then required to recall the analog concept (e.g. water pipe).
3. The learners shall identify similar features of both concepts (e.g. current).
4. These similar features are mapped (e.g. by drawing a table).
5. Conclusions are drawn about the concepts.
6. It is indicated where the analogy breaks down (e.g. behavior of open circuit).

Bridging Analogy: Analogy relations may sometimes fail to be recognized by learners. In this case, intermediate situations may be introduced between the analog and target concept (so called bridging analogy).

The authors of this study consider that the findings about analogies may also be applied to similarities of concepts (for example in the context of forces and geometry). In the Discussion, we support this view further as we compare our results with former research about analogies.

Application of Similarities (Including Analogies) in Combination with Discovery Learning

The TWA-model may be considered as an appropriate means for explicit-reflective inquiry (or discovery) learning along the lines of Khishfe and Abd-El-Khalick (2002). A similarity (with its correspondences and differences) is a form of general principle. Therefore, transfer is expected to occur with respect to this "similarity thinking", and the "explicit approach" relies on the TWA-model.

So far, there has been a lack of experimental studies concerning similarity-based discovery learning. Though Flick (1991) did explicitly use analogies in discovery learning, this was not implemented as an experimental study. Lin et al. (1996) employed teacher-based pictorial analogies according to the TWA-model. Different social forms were run during the examined lessons: presentations by the teacher, questions addressed to the class, and discussions in small groups. Regarding conceptual performance, an improvement of up to three standard deviations was measured. However, the experimental and the control group were not taught by the same teachers, and the influence of the applied learning forms on the effect was not investigated.

Objective and Hypotheses

Until now there has been a lack of objective comparison between different learning forms for the use of similarities. In particular, it has remained unexplored as to which extent similarities, in combination with guided discovery learning, may foster conceptual performance when presented in a written assignment for individual learning (similarity-based guided discovery learning). In fact, there was no guarantee that similarities (including analogies) act independently of the employed learning form. So if the choice of the form came to interfere with the effect of similarities, concept learning could well be affected. Especially the time required for thinking might have an impact on how effectively concepts are acquired.

This study therefore aims to examine the combined effect of similarity and learning forms (guided discovery learning vs. expository learning). It is designed as an experimental and double blind study.

In this study, guided discovery learning was conceptualized according to the taxonomy of Domin (1999).

The following hypotheses were investigated in this study:

Hypothesis 1: Similarities are as effective in the case of guided discovery learning as they are in the case of direct teaching, even if the time available for learning is not any longer.

Hypothesis 2: The effect of a similarity on concept learning is particularly large if study material challenges the learners (difficulty level as a parameter). Conversely, we would expect no effect in case of extremely easy material.

Hypothesis 3: The use of similarities affects concept learning stronger than the learning arrangement applied (here: expository or guided discovery learning). Discovery learning alone is not sufficient to simultaneously foster transfer and concept understanding.

Method

Sample

There were 298 young students (8th- and 9th-grade students) from eight Swiss-German schools participat-

Table 1
Study Design with Four Groups

Variables	Discovery	Teaching Text
With similarity	Variation SD (experimental group) $n = 77$	Variation ST (experimental group) $n = 65$
Without similarity	Variation ND (experimental group) $n = 83$	Variation NT (control group) $n = 55$

ing in this study. The schools were partly in urban, partly in rural environments, and were located in three different cantons. The experiment was conducted by 12 teachers who taught the classes on a regular basis. For the final analysis, 280 students who met the following criteria could be included.

The authors and evaluators were excluded from participation as teachers; teachers and students were not informed about the goals of the study (double blind study). The experiment was integrated into the regular lessons and teaching environment. Data collection took place in July 2004 and between April and July 2005. The study design was experimental, i.e. the students of the 14 participating classes were randomly distributed to the different groups of the experiment, one of which served as control group (2005: four groups; 2004: two groups). In each class, the participants (who were assigned to different groups) worked simultaneously, silently and without any interaction, during the intervention and the tests. The intervention was in form of written assignments. The role of the teacher was to care for correct organization and timing. Explanations of the teacher were restricted to the introduction before the actual investigation.

Material

For this study the first author developed four different variations of written material for the learners. All documents were written in German. We first give a brief description and then present the more detailed content of each of the four variations. The first variation combined similarity and discovery learning (Variation SD). In this variation, an assignment for guided discovery learning was offered with a high degree of guidance due to goal-related questions and especially due to helpful figures. The assignment guided the learners to a predetermined similarity of concepts (proportionality) by using questions and pictures, and in accordance to the TWA-model. The similarity was between the geometry of similar triangles and the physical behavior of a bicycle on the inclined plane. The second variation combined similarity and teaching text with interspersed questions (Variation ST). By direct mediation, the Variation ST learners were confronted with a given description and interpretation of the before-mentioned similarity. The third variation showed no similarity but discovery learning (Variation ND). The learners received the same material as for Variation SD, but without reference to any similarity. Instead of the explicit question concerning the similarity, an alternative problem was posed on the same topic ("target" concept). The fourth variation showed no similarity but teaching text (Variation NT). As in Variation ND, the similarity was replaced by alternative information. Moreover, the learning form was the same as in Variation ST.

In 2004 the variants SD and ND were presented to the participants, in 2005 all four variants. Table 1 shows the study design (a 2×2 factorial design).

All four variations of assignment were comparable in terms of amount, structure and number and kind of figures. The assignment and all other materials for the students were examined in respect to physical correctness and adequate domain specific logic structure (physics / didactics context) by two didacts of physics from the ETH Zurich (experts). On average, the students worked on the assignment for 17 minutes (± 3 minutes). The time spent on the assignments did not differ significantly between the four groups.

During the experiment a construction figure of the target concept was projected (and was used as first step according to the TWA-model).

Content of Variation SD (first experimental group).

Two pictures represent similar objects (Figure 1: Target – inclined plane; Figure 2: "Analog" – similar triangles). The learners have to find out how the labeled sides of the triangles relate to each other (second step of the TWA-model). In this way, the learners are led to the concept of proportionality (or similarity). Subsequently, they have to search for the intended "similarity relation" (which does not appear in proper words in the instructions, however). The learners note correspondences and differences (third, fourth and sixth step of

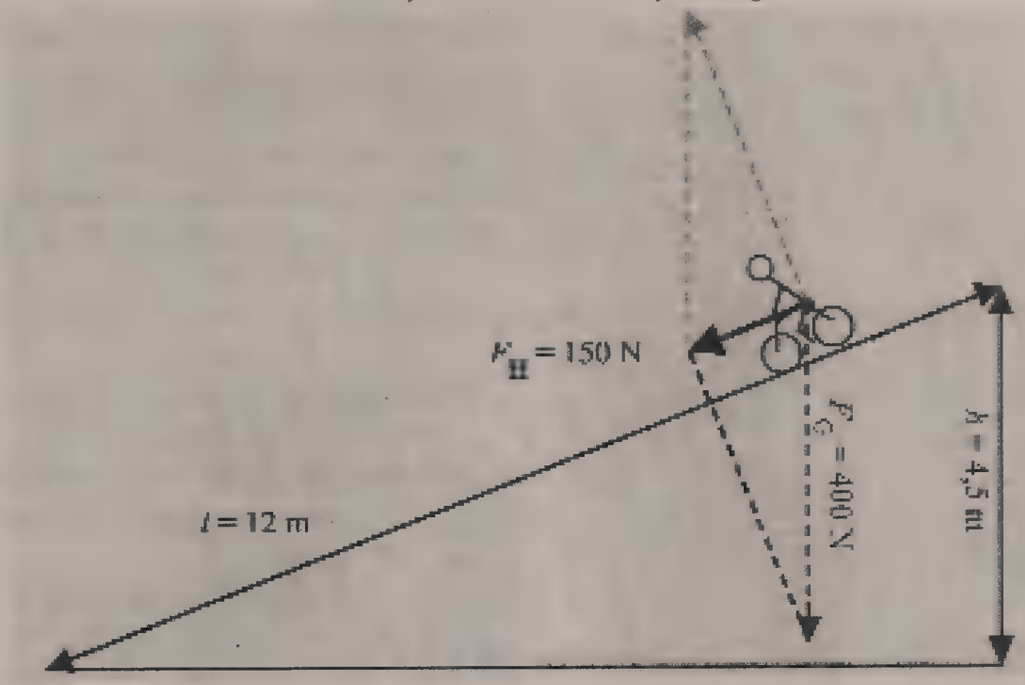

Figure 1. Target - inclined plane with sloping site and parallelogram of forces (Version 2005).

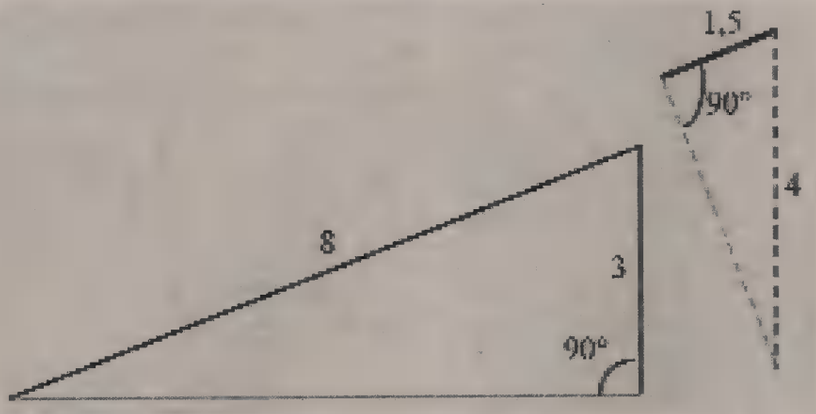

Figure 2. "Analog" - similar triangles (Version 2005).

the TWA-model, respectively). Noting correspondences makes the learners aware of the usefulness of the similar concepts. Consequently, they have to find the relation between the forces and lengths for the inclined plane (fifth step of the TWA-model). This relation corresponds to the concept of proportionality, yet in a different situation. All requirements of the TWA-model are fulfilled at this point. Subsequently, the learners check their discovery (target concept) with examples of their own choice. These freely chosen examples should allow for a deeper insight into the similar concepts. Finally, the learners resume their discovery in an abstract form (proportionality / formula). The goal of this activity is that participants fully understand and explain the meaning of the proportionality relation in the context of the inclined plane. On average, if learners encountered increasing difficulty during discovery learning, they had a lower chance to find the correct proportionality relation, expressed as a formula. For this reason, the rate of finding the correct formula appeared to be helpful to compare the difficulty of different versions of assignments.

The content of the assignment is as follows (texts are in quotation marks and translated from German; the answers given by participant number 286 are shown as an example in quotation marks):

Part 1: "Consider the following triangles" (Figure 2).
"Complete the following calculation, so that it corresponds to the figure: 1.5 : … = 3 : …"
Answer by participant: "1.5 : 4 = 3 : 8".
Part 2: "The steep street" (Figure 1).
"What are the correspondences between this steep street and the triangles of Part 1?"
Answer by participant: "Right angle triangle; the smaller one is the triangle which determines F_H, the larger one is the street."
"Where is a difference?"
No answer by participant.
"Is there a similar calculation as in Part 1? What is it (with numbers)?"

Answer by participant: "4.5 : 1.2 = 4 : 1.5".
Part 3: "Draw a street yourself – make it either steeper or flatter! Take the same bicyclist as in Part 2!"
Participant draws a steeper inclined plane.
"What is the difference of your street compared to Part 2?"
Answer by participant: "Mine is steeper".
"Draw the forces again!"
Participant draws a small triangle with the forces F_G and F_H.
"How large are here: l = …, h = …, F_G = …, F_H = …"
Answer by participant: "l = 10 m, h = 7.5 m, F_G =3.5 m, F_H = 2.6 m".
"What is the calculation here?"
Answer by participant: "7.5 : 10 = 3.5 : 2.6".
"...Replace all numbers by the corresponding symbols l, h, F_G, F_H:"
Answer by participant: "$h : l = F_G : F_H$".

Unfortunately, participant number 286 did not (fully) succeed in finding the correct proportions, although the participant could partly take advantage from the similarity (the participant also confirmed this by the qualitative questionnaire). Moreover, the participant mistook the forces for lengths. This problem might have been avoided, if the participant had stated at least one difference between Figures 1 and 2 in Part 2.

Content of Variation ND (second experimental group).

Variation ND differs from Variation SD in a substitute depiction with a different accompanying text (see Figure 3) instead of Figure 2. The substitute depiction represents an inclined plane in which the subjects have to identify and measure two identical acute angles. Variation ND does not explicitly lead to any similar features, but has the same extent as Variation SD.

The content of the assignment is as follows: Part 1: "In this figure (Figure 3), the resulting force F_H is composed of the components F_G and $F_\perp$. Measure the angle α: α = … Find a further angle of equal size as α. Label the angle as β. Check by measuring the angle: β = …" Part 2: "The steep street" (Figure 1). "Complete the following calculation, so that it corresponds to the figure: 150 : … = 4.5 : …" Part 3: This part is identical to Part 3 of Variation SD.

Content of Variation ST (third experimental group).

Variation ST corresponds to a standard teaching text with interspersed questions. The content is exactly the same as for Variation SD, except that learners do not have to discover anything in Variation ST. Instead, similar and dissimilar features of "analog" and target are explained, and the proportionality relation is shown.

The content of the assignment is as follows: Part 1: "Introduction: Consider the following triangles (Figure 2). The numbers fulfill a simple relation: 1.5 : 4 = 3 : 8. Check the side lengths with a ruler. Label the measured lengths near the sides." Part 2: "The steep street" (Figure 1). "In this steep street, there are similar triangles as in Part 1: one larger and one smaller triangle. Draw the right angles. Label in Part 1 the sides with the symbols l, h, … corresponding to the sides of Part 2. Yet there is also an important difference: The paral-

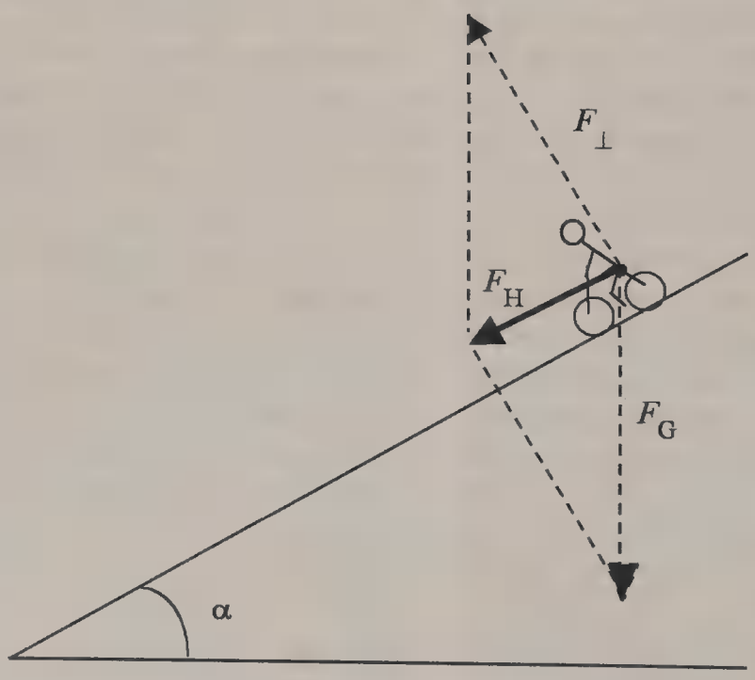

Figure 3. Substitute representation instead of Figure 2 (Version 2005).

Table 2
Sequence of the Various Experimental Stages

Point in time	Stage
1. Before pre-test	Make sure that necessary requirements are met (similarity of triangles; vector addition of forces)
2. 1 week before intervention	Pre-test
3. Beginning of intervention.	Intervention (four variations of assignment)
4. Immediately after intervention.	Post-test
5. Immediately after post-test.	Qualitative questionnaire

stages 3, 4, and 5 took place within one lesson.

lelogram is made of arrows of forces. Forces are something else than the lengths of the triangle sides of Part 1. For this steep street, the calculation is: 150 N : 400 N = 4.5 m : 12 m. Does this calculation correspond to the one in Part 1? Look for the side "150 N", then the corresponding side in Part 1, underline its value in the calculation. Etc." Part 3: This part is identical to Part 3 of Variation SD.

Content of Variation NT (control group).

Variation NT corresponds to a standard teaching text with interspersed questions. In respect to learning content, ND and NT correspond. Of all four assignments, Variation NT resembles most to the average usual teaching practice (for a characterization of regular classes see e.g. Hage et al., 1985, p. 76–87).

The content of the assignment is as follows: Part 1: "In this figure (Figure 3), the resulting force F_H is composed of the components F_G and $F_\perp$. Measure the angle α: α = …" In the figure, one of the acute angles of the parallelogram has been marked as β by the main author. "Measure the angle β: β = … The angle β is of equal size as α. There is another angle of equal size: Label it." Part 2: "The steep street" (Figure 1). "Street length: l = …, street height: h = …, weight force: F_G = …, force along the inclined plane: F_H = … In this figure, the numbers fulfill a simple relation: 150 N : 400 N = 4.5 m : 12 m. Check the side lengths with a ruler. Label the measured lengths near the sides. Put your measured values above." Part 3: This part is identical to Part 3 of Variation SD.

To test the second hypothesis, the difficulty level of the tasks was slightly varied between the years 2004 and 2005. The rate of finding the correct formula was used as an indication of the difficulty. Figures 1 and 2 show the less demanding version of 2005. With this version, 72% of the students came up with a correct formula of the assignment. The year before, one of the four numbers appearing in the depiction was removed (in 2004, there were Variations SD and ND only). Only 51% of the students came up then with the correct formula. Therefore, the version of 2004 was on a higher level of difficulty. Unlike the assignments, the pre-tests and post-tests of 2004 and 2005 were corresponding. Thus it was possible to analyze the influence of changing the level of difficulty on concept performance.

Procedure

Seven days before the experimental intervention with the assignment, subjects underwent a uniform pre-test (only 2 days before for two classes with a total of 45 students, and 4 days in advance for one class with 22 students). During the experimental intervention, the subjects received only written information (assignment). Subjects underwent a uniform post-test after completion of the intervention. The questions of the post-test were preceded by a restatement of the end formula of the intervention assignment, thus ensuring that every participant could theoretically answer the questions. After the post-test, a qualitative questionnaire had to be filled out. Closed and open questionnaire items revealed, to which extent the learners benefited from a similarity. Subjects kept the documents of the experimental intervention until all parts of the experiment were completed (in the course of one lesson). The pre-tests and post-tests however, were collected immediately after the lapse of time (7 minutes each). The role of the teacher was to organize the lesson according to the study design.

Table 2 shows the sequence of the various experimental stages.

Instruments

Both the pre-test and the post-test collected the following two variables with corresponding score scales and types of questions, for all groups:

The "algorithmic variable" concerned the application of new problem-solving procedures (construction of parallelogram). The question in the pre- and post-

test is (text in quotation marks is translated from German): "Complete the construction of parallelogram of forces in the following figure …". In the pre-test, the figure represents the inclined plane, the weight force F_G and the line of force perpendicular to the inclined plane. In the post-test, the figure represents the inclined plane, the force $F_\perp$ perpendicular to the inclined plane and the line of force of the weight force F_G.

The "concept variable" referred to conceptual performance in the sense of complete comprehension of a functional relation (here: proportionality with an existing "analog" in the geometry of triangles). The questions in the pre-test are (translated from German): "The street could also be flatter than in the figure above" (same figure as for the algorithmic variable). "Would the resultant force F_H be larger, smaller or equal compared to the figure? Give the reasons for your answer in a short sentence and using F_H etc. How could we make F_H larger without modifying the steepness?" The questions in the post-test are: "What does the above relation express?" ($F_H : F_G = h : l$) "Complete the following sentences. 1. If the height h is higher at constant length of the street, the street is steeper and therefore … 2. If the street is longer at constant height, … 3. Also vary something else than h or l: … 4. Why does this rule apply to any situation? Make a few sentences."

In a certain sense, learning with or without similar concepts may be considered as a matter of problem solving strategy (the same consideration may also apply to former studies, see for example Lin et al., 1996). But similar concepts may also act on concept understanding. In contrast, problem solving strategies are not necessarily related to comprehension of a concept. That is why some of the test items above are not related to problem solving ability, but characteristic for the concept variable.

To avoid mere repetitions, the questions of the post-test are slightly different from those of the pre-test, although of the same type. The main author divided the expected solutions into equal solution steps, each step corresponding to one scale point for the evaluation.

The pre-test and the post-test were designed in such a manner that, on average, the learners attained about half of the scores (based on pilot tests). Thus a difference between pre-test and post-test cannot actually be interpreted as an "improvement" or "loss" of competence (in case of positive or negative difference, respectively).

In addition, the algorithmic variable was used to test whether differences in algorithmic solving ability resulted from the variations of assignment used in the intervention. If all variations were constructed to be fully equivalent except for the above-mentioned intentional differences, no differential effects should be found for the algorithmic variable. A confirmation is given in the results section.

Test rating.

Two raters independently evaluated the algorithmic and the concept variable in the pre- and post-test according to a rating scheme (two physicists holding at least a bachelor degree; the authors, experts and investigating teachers were excluded).

The two independent ratings corresponded well (Cohen's Kappa: 0.8). Consequently, we calculated the average of the two ratings for all scores and used this for further analyses. Statistical evaluation was then performed on the four groups (SD, ST, ND, NT) using 2×2 ANOVA and multiple group comparison techniques.

Group comparability in the pre-test.

Before the main evaluation, equivalence of learning conditions of the four groups was tested. We first checked that the groups were on comparable levels of performance in the pre-test. None of the two variables yielded any significant difference at the .05 level, algorithmic variable: $F(3, 279) = 1.33, p > .2$; concept variable: $F(3, 279) = 1.02, p > .3$. Nor did a multiple comparison between the four groups yield any significant differences ($p > .05$).

Additionally, averaged grades in physics and mathematics were collected. They correlated significantly with the algorithmic variable in the pre-test scores (grades in physics, $r = .22$; grades in mathematics, $r = .20$). The grades in physics also correlated significantly with the concept variable in the pre-test scores ($r = .16$).

Results

From this point, we accounted for pre- and post-test data and thus introduced the time dimension (repeated measures). We also referred to the 2×2 factorial design shown in Table 1. So we conducted a 2×2 repeated measures ANOVA with similarity (with similarity, without similarity) and discovery learning (with discovery learning, without discovery learning) as the two repeated-measures factors. In some cases, we additionally sought for possible interaction-time-effects. An alpha level of .05 was used for all tests.

Algorithmic variable

We first tested whether the variations of assignments

could cause undesired differences in algorithmic solving ability in the post-test. No significant differences could be found for the algorithmic variable between the four groups, $F(3, 279) = 0.90, p > .4$, multiple comparison between groups: $p > .1$. Moreover, no significant interaction-time-effect was observed ($p > .7$). Up to this point, all necessary tests had been completed to indicate equivalent learning conditions for all groups.

Concept variable

We shall now present the main results concerning the concept variable in the post-test.

Before testing our three hypotheses, we compared the scores of the different groups.

We found a significant group effect, $F(3, 279) = 2.74, p < .05$. A multiple comparison between groups yielded differences as follows: Group SD lay 0.45 points higher than Group ND in the score (LSD-test: $p < .01$; Bonferroni-test: $p < .05$); Group ST lay 0.36 points higher than Group ND in the score (LSD-Test: $p < .04$).

This means that both groups with similarity reached better scores than did the discovery learning group without similarity.

No further significant differences were found between the other group pair combinations ($p > .05$).

The result of the univariate analysis was in accordance with the measured interaction-time-effect with respect to the concept variable ($F = 2.73, p < .05$). That means that the scores with similarity also showed more progress with respect to the pre-test scores.

Table 3 shows the averaged scores of the concept variable in the post-test for all four groups (on a scale from 0 to 5). The highest score was obtained by the discovery learning group with similarity (SD). The lowest score was reached by the discovery learning group without similarity (ND).

We also compared the scores with and without similarity. To do this, we joined both groups with similarity to form a "similarity group" and both groups without similarity to form a „non-similarity" group, respectively. We found a significant improvement of 0.31 points in the score in favor of the similarity group, $F(1, 279) = 6.16, p < .02$: The difference was 0.3 standard deviations. Considering the interaction-time-effect, a slightly stronger effect appeared ($F = 7.94, p = .005$). To conclude our evaluation, we routinely checked for undesired effects on the similarity and non-similarity groups. Regarding the algorithmic variable in the post-test as well as the algorithmic and conceptual variables in the pre-test, all differences were not significant ($p > .2$). There was no observable interaction-time-effect on the algorithmic variable either ($p > .8$).

Test of Hypothesis 2: In this test, we analyzed how the effect of similarity of concepts changed depending on the difficulty of the assignments. In 2004 the difference was 0.72 scale points for the 37 subjects, $F(1, 36) = 6.35, p < .02$ (assignments in 2004 comprised of less numbers in the depictions and were therefore more demanding compared to 2005). The score difference in 2004 was considerably larger then the score difference in 2005. This means that the similar concepts were more effective when applied in conjunction with a higher degree of difficulty (assignment yielding 51% success only). Hypothesis 2 was confirmed.

Test of Hypothesis 1: We did not find any signs indicating that similar concepts would be less effective when presented within discovery learning compared to teaching texts (difference between SD and ND: 0.45; difference between ST and ND: 0.36). Hypothesis 1 was confirmed.

Test of Hypothesis 3: We postulated that similar concepts had a stronger action on concept learning than did the variation of learning form (direct mediation with teaching texts or guided discovery learning). We thus checked whether discovery learning influenced the scores substantially compared to teaching texts. Overall, we found no significant difference between discovery learning and texts, $F(1, 279) = 0.51, p > .4$. Even with the comparison confined to samples with similarity (SD compared to ST) and without similarity (ND compared to NT), there was no significant difference. We again concluded the evaluation with a routine check for undesired effects. Discovery learning did not differ from teaching texts in respect to either the algorithmic variable in the post-test or to the algorithmic and concept variable in the pre-test ($p > .5$). Neither

Table 3

Means (Standard Deviations in Parentheses) of the Concept Variable in the Post-Test

Concept variable	Discovery	Teaching text
With similarity	2.05 (1.19)	1.96 (1.00)
Without similarity	1.60 (1.00)	1.85 (1.03)

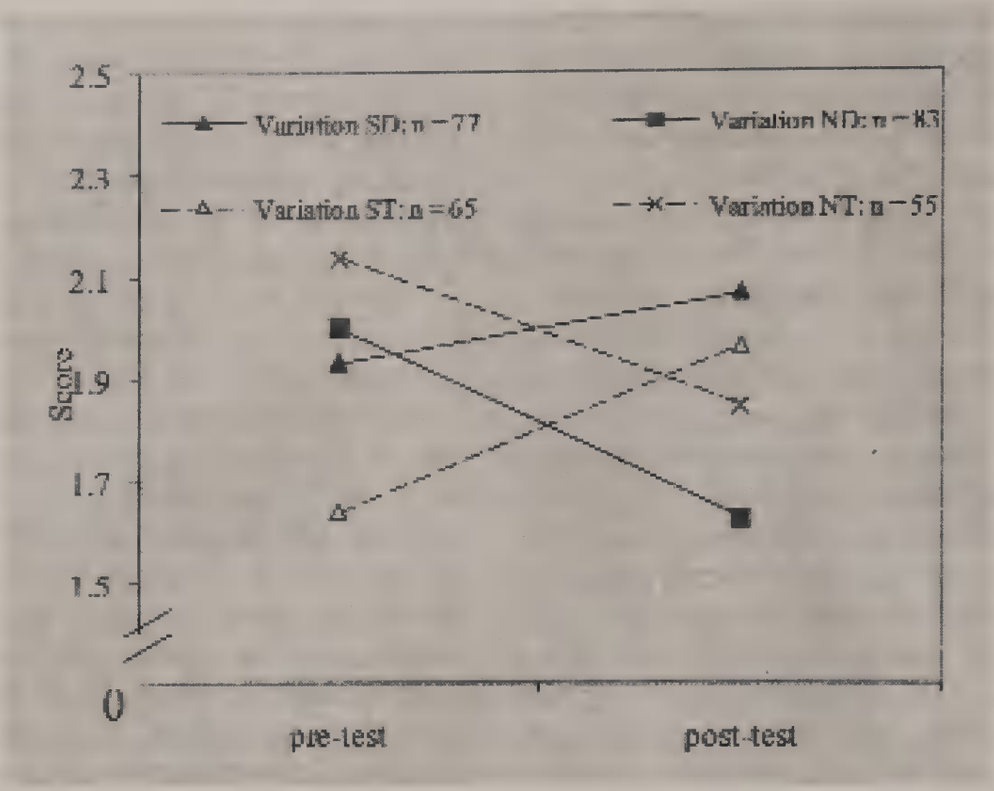

Figure 4. Temporal changes on the concept variable (means in the pre-test and post-test).

did we find any significant interaction-time-effect regarding the algorithmic or concept variable ($p > .3$). In summary, the learning form did not have any noticeable effect on concept learning. So Hypothesis 3 was confirmed.

Temporal changes on the concept variable.

The overall trends of the concept variable can be summarized as follows. We observed a general positive trend for the groups with similarity, compared to the groups without similarity. Within Group SD and Group ST, the means tended to increase from pre-test to post-test (positive trend, with similarity). Within Group ND and Group NT, a diminution of means could be observed from pre-test to post-test (negative trend, without similarity). Figure 4 illustrates this observation. The observed trends correspond to the significant interaction-time-effects which we already have quantified in the main results (group effect and effect of similarity group).

Discussion

In accordance to former empirical data about analogy learning, our study showed that the similarity of concepts allows improved conceptual performance (similarity structured according to the TWA-model). The effect was still observed when the similarity of concepts was included into guided discovery learning. In addition, we were able to show that the effect is more important when the level of difficulty in the intervention is raised.

As discovery learning is adequate to foster transfer, and as similarity of concepts remains powerful when combined with discovery learning, similarity based discovery learning should be recommended for practice. Furthermore, analogies and similar concepts including the TWA-model make the intended transfer goal explicit.

For us, the results of this study indicate the need for an appropriate cognitive structuring aid for discovery learning (see also Mayer, 2004). In our case, similar features served as a structuring aid. We are, however, of the opinion that it is not sufficient to briefly mention similar features, metaphors or analogies (Glynn, 1989). Rather, guiding aids have to be integrated explicitly. The TWA-model was already used in the past as a guiding aid. The assignments of this study were constructed on this basis. In our view, the TWA-model represents more than a problem solving strategy, as it fosters concept comprehension. In particular, the TWA-model may be necessary for successful analogy mediation, regardless of the chosen learning form.

In this study, two very different learning arrangements were used (guided discovery learning and teaching texts with interspersed questions). However, we could not find any indication that the choice of specific learning arrangements could influence the effect of

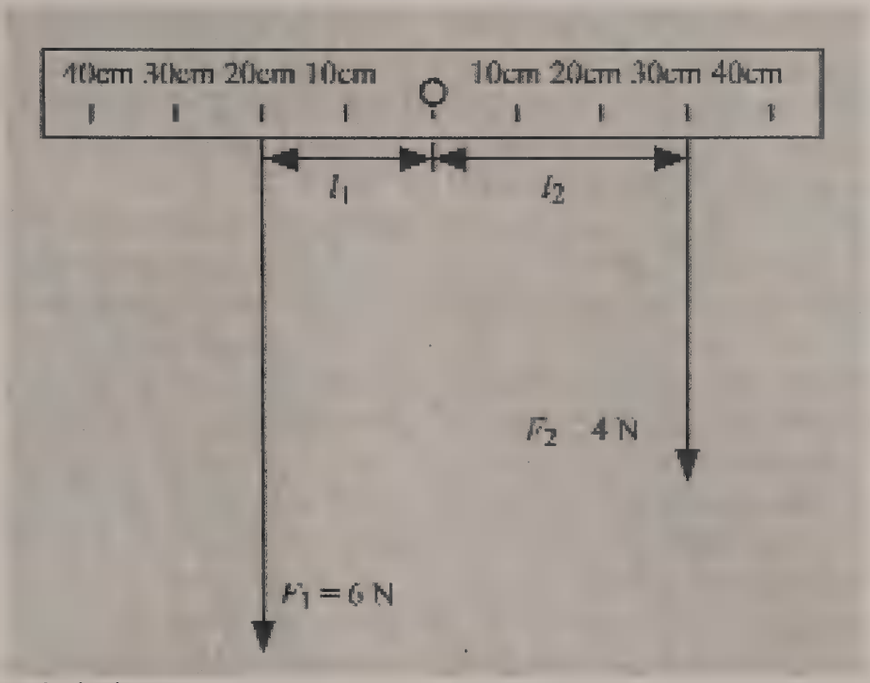

Figure 5. Target - lever in balance.

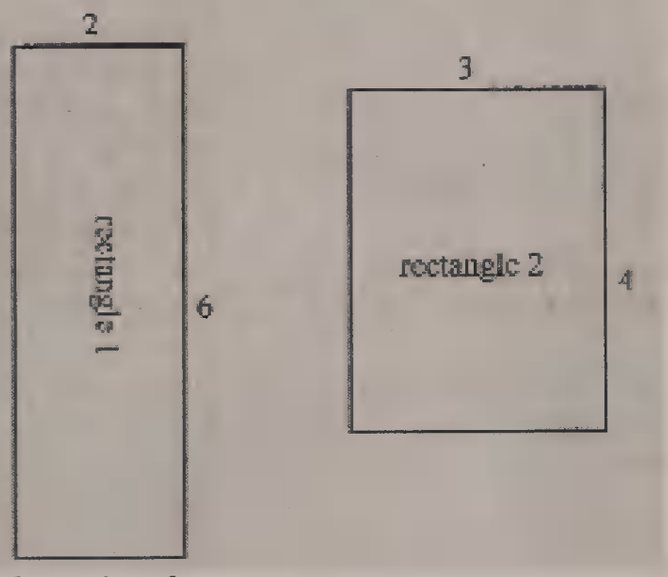

Figure 6. "Analog" - rectangles of equal surface.

similar concepts significantly. This means that no interference between the employed learning form and the learning with similarities is apparent.

The results presented here are concerned with the concept of proportionality in physics. Further concepts could be applied in a similar way, although they were not subject of this investigation. For example, the inverse proportionality could be implemented in connection with the law of the lever (Figure 5): Instead of the similar triangles depicted above, rectangles of an equal surface would be used in the "analog" (Figure 6). The forces (F_1, F_2) correspond to the vertical sides of the rectangles, the lever arms (l_1, l_2) to the horizontal sides of the rectangles. The delineated construction of assignments can then be immediately transferred. The learners would have to find an equation for the inverse proportionality from Figure 6, compare Figure 5 and 6 (similarities and differences), induce the relation between forces and lever arms according to Figure 5, generate a new example of their choice and summarize their findings. As for the inclined plane, more demanding assignments can arise by presenting less than the four numbers shown in the depictions. With assignments of this kind, we would expect a similar effect as in our study.

In a similar manner, the analogy of two physical concepts may also be introduced. For example, a water circuit might be depicted instead of the similar triangles of our study, and an electrical circuit would appear instead of the inclined plane. The learners would have to

find differences and correspondences for concepts like current, tension / pressure and resistance. They would have to draw circuits with large and narrow water pipes (and thus low and high resistance). They should then be able to explain, for example, how the electric tension and the current affect the resistance.

As former studies already found a significant effect of various analogies on concept performance, we expect those findings to apply more generally, when discovery learning is associated to analog or similar concepts. However, confirmation of this generalization would need additional experiments.

Due to the results we assume that the effect produced by analogy learning might be fundamentally independent of the teaching methods applied. To ensure that our findings can be generalized on a wider range of learning forms or methods, one would have to test additional methods or variations systematically (such as, for example, problem-based learning or more open discovery or inquiry learning).

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Mix It Up: Teachers' Beliefs on Mixing Mathematics and Science

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This paper defines correlation, describes the Mix It Up program, discusses the teachers' beliefs about the value of correlating mathematics and science prior to program participation, and identifies problems teachers associated with correlation before and during the program. Teachers' beliefs about the value of correlation and about the problems associated with correlation are based on results from both quantitative and qualitative methods used to evaluate the program. Results indicate that teachers believe correlating mathematics and science strengthens students' content knowledge in mathematics and science, bridges the gap between mathematics and science, enhances motivation, and increases students' flexibility in problem solving. Additionally, the areas identified by teachers to be most problematic were time, planning for instruction as a team, and exposure to correlation in the past. The most important finding from the program evaluation indicates that although teachers did not identify content knowledge weaknesses before participating in the program, they did recognize gaps in their own content knowledge during program participation, and more importantly they made connections among these gaps, classroom instruction, and their own students' performance in mathematics and science.

Mix It Up is a program aimed at (1) providing intense, sustained, systemic, correlated mathematics and science content knowledge and skills, and (2) recruiting and maintaining middle school teachers. In order to accomplish these goals, we invite teacher teams to participate in mathematics and science summer programs and academic-year, follow-up sessions. This paper defines correlation, describes the *Mix It Up* program, discusses the teachers' beliefs about the value of correlating mathematics and science prior to program participation, and identifies problems teachers associated with correlation before and during the program. Teachers' beliefs about the value of correlation and the problems associated with correlation are based on results from both quantitative and qualitative methods used to evaluate the program.

Definition of Correlation

Correlating mathematics and science is extending the concept of integration. Traditionally, integrating mathematics into a science class consists of science teachers using mathematics as a tool and integrating science into a mathematics class consists of mathematics teachers using science applications (Davison, Miller, & Metheny, 1995). While correlation is characterized by the traditional sense of integration, correlating mathematics and science also includes

- both mathematics and science learning objectives clearly linked to state and national standards (See Content Specific Integration in Davison, Miller, & Metheny, 1995.),
- language issues (Francis & Underhill, 1996; Vasquez-Mireles, 2007), and
- a focus on the conceptual nature of the model (Hurley, 2001; Vasquez-Mireles, 2007).

To be a correlated mathematics and science lesson, both mathematics and science learning objectives must be clearly identified and direct the instruction. For more information on this process and specific steps on how to develop integrated and correlated mathematics and science lessons, see Francis and Underhill (1996), Lonning, DeFranco and Weinland (1998), and Vasquez-Mireles and West (2007). After the learning objectives are defined, teachers can then begin teaching the concepts to each other. As the mathematics teacher teaches the mathematics concepts and the science teacher teaches the science concepts, conversations around language, parallel ideas, and misconnections will arise. Teachers will learn that sometimes the same words are used in mathematics and science, but they have different meanings (e.g., regular object) or that different words are used, and they have the same meaning (e.g., distance in mathematics and displacement in physics). In terms of conceptual connections, Vasquez-Mireles (2007) has identified two in particular: parallel concepts and misconnections. Parallel concepts in mathematics and science have parallel relationships (e.g., zero and no acceleration in science are parallel to zero and no slope in mathematics). Also see Hurley's (2001) discussion on defining integration as it relates to parallel concepts. Misconnections are concepts

in mathematics and science that exemplify misconceptions, contradictions, or common errors (e.g., soil is represented as a homogeneous composition of clay, silt, and sand, whereas a fraction model represents these parts distinctly).

Program Background and Teacher Participants

The *Mix It Up* participants are in-service, middle school teachers from all over the state of Texas. *Mix It Up* teachers participated in intensive summer training programs on the Texas State University – San Marcos (Texas State) campus during June 2006 and June 2007. The Program was partially funded by the Teacher Quality Grant beginning in May 2006 and by the Fund for the Improvement of Post Secondary Education (FIPSE) beginning in October 2006. Procurement of additional funding has allowed expansion in terms of the number of participants and the duration of the program. In the spirit of collaboration, the teachers received room and board, a stipend, and support to attend professional conferences while engaging in mathematics and science correlated lessons. Teachers observed professors at Texas State using the correlated mathematics and science model to team teach mathematics and science lessons. The faculty also explained how current research supports the model and identified specific components that make up the model. The teachers engaged in hands-on investigations and activity-based labs. Correlated lessons included technology and hands-on field trips where the professors modeled correlation in real-world situations (e.g., amusement park mathematics and physics at Fiesta Texas and life science and sequences at Aquarena Springs). Teachers also attended professional conferences (e.g., Conference for the Advancement of Mathematics Teaching and Conference for Advancement of Science Teaching). Most importantly, the teachers were required to develop their own mathematics and science correlated lessons as a team, teach the lessons to their peers, and receive feedback.

During the academic year, teachers were asked to continue developing and teaching correlated lessons. Teachers were instructed to self evaluate their correlated lessons plans and collect and analyze students' work samples and reflections. Additionally, program faculty observed teachers in their classrooms. Teachers also took part in monthly academic-year, follow-up training sessions. Topics covered during the academic-year sessions included content-specific instruction, leadership activities, and lesson plan writing sessions.

A variety of data sources were collected and analyzed. First, a survey was administered that assessed teachers' initial beliefs about using correlated mathematics and science lessons in the classroom prior to participation in the program. A total of 30 teachers completed a pre-survey administered at the beginning of each summer session (10 teachers in June 2006 and 20 teachers in June 2007). Teachers who participated in both summer sessions were only surveyed regarding initial beliefs in the first summer they participated. For the pre-survey, descriptive statistics were used to analyze the quantitative data and themes emerged from the qualitative data after coding specific comments made by teachers. Two other sources of data were used to support the argument in this paper. First, paired t-tests to analyze pre- and post-tests to measure gains in both mathematics and science content knowledge after teachers participated in the program were conducted. Second, daily reflections were coded and analyzed and confirmed trends. Since two of the data sources are based on teacher comments and emerging themes, it is important to note that a limitation of this study is its generalizability to a larger population. However, as the study is repeated each summer, and if these themes continue to emerge as predicted, then this will strengthen the generalizability of these results.

Why do teachers believe it is important to correlate mathematics and science?

Of the 30 program teachers, 50% (15 teachers) reported that they did not correlate mathematics and science in their lessons, 43% (13 teachers) reported that they did, and 7% (2 teachers) did not respond to this question. Of those teachers who did correlate mathematics and science, this was done once or twice a week at most. Later, after teachers gained more knowledge about what it means to correlate mathematics and science, class discussions revealed that most teachers had experience integrating mathematics and science lessons, and not necessarily "correlating" the lessons. This misunderstanding of what it truly means to correlate is supported by selected comments from the pre-survey. Comments were collected from the following prompts to which teachers responded:

- What reasons would you have for having students participate in correlated learning?, and
- What do you think is the value of correlated learning in mathematics/science?

The following sample responses support the idea of mathematics as a tool in science classrooms:

"A lot of science has mathematics involved. What I have found is that students cannot do the science be-

cause they do not have the mathematics background needed. The students would be learning how to apply mathematics concepts in science."

"Mathematics and science are closely related. There is a good deal of mathematics in most science courses and we should be able to help each other."

"Mathematics and Science overlap in so many ways. To do science you have to know mathematics."

These are sample responses that support the notion of using science applications in mathematics classrooms:

"Real world connections/ applications. It's important to see the different ways to get the same answer."

"Students can make real world applications between mathematics and science"

"The value would be incorporating higher level skills. Application of concepts (in mathematics) to real world problems"

All teachers wrote fluidly about the benefits of having students learn mathematics and science through correlated lessons. The teachers proposed that correlated lessons would strengthen students' content knowledge in mathematics and science, bridge the gap between mathematics and science, enhance motivation, and increase students' flexibility in problem solving. These opinions expressed by *Mix It Up* teachers are similar to those reported by other researchers (Beane, 1993), and student enthusiasm for integrated mathematics and science lessons is also documented (Haigh & Rehfeld, 1995). However, few studies actually provide empirical evidence for gains in content knowledge and problem solving (Berlin & Lee, 2005; Hurley, 2001; West, Vasquez-Mireles & Coker, 2006). These are sample comments from teachers describing how they believe correlated lessons will benefit their students:

"Based on what I know about correlated learning, it is an excellent teaching and learning strategy. Students have a better chance of learning the concepts both in mathematics and science because they have extended methods and there are two teachers collaborating. It also makes both mathematics and science classes interesting. Here students can apply the mathematics skills in real situations. They will help the students understand that education is important in human lives."

"I believe that the strategy will help the students learn more. They will be able to realize that mathematics and science are related and dependent on one another. I also believe that the students will be motivated more to learn and participate because the activities will be more exciting and interesting. "

"The value of correlated learning in mathematics and science is very high. it develops those subject area skills in students, allows for hands on learning, an is a great for team building."

"Reinforcement of science TEKS, Reinforcement of mathematics TEKS, broadens understanding of science concepts, and helps students to think analytically."

"The value is that it helps students to gain understanding of both concepts (mathematics/ science) relationship."

Results from the pre-survey suggest that these teachers are good candidates for learning how to develop and implement correlated mathematics and science lessons since they believe correlating mathematics and science will strongly benefit their students. These results are not surprising given that the teachers chose to participate in such an intense summer professional development program that focuses on correlating mathematics and science lessons. However, some program faculty reported a lack of motivation for some teachers and informal conversations lead us to believe that the teacher stipends may have also played a role in motivating teachers to participate in the program. Motivation for participation in the program needs to be examined more closely the next time the survey is administered. In addition to exploring teachers' beliefs about the value of correlating, the pre-survey identifies problems teachers have encountered with correlating. The next section will address these problems.

What problems have teachers encountered with correlating mathematics and science?

Several problems with correlating were identified by existing literature and experiences of the program faculty (Czerniak, Weber, Sandmann, & Ahem, 1999; Huntley, 1999; Mason, 1996; Meier, Cobbs, & Nicol, 1998; West, et al., 2006). Teachers were asked to rank

Table 1
Number of Teacher Responses for Each Ranking

Scale	1	2	3	4	5
Time	6	6	3	1	0
Coordinating of students	3	6	6	0	1
Planning for instruction as a team	8	3	2	1	2
Coordinating of student assessments	4	4	5	3	0
Availability of models and/or materials	5	1	3	5	2
Communication	2	6	6	1	1
Exposure to correlation in the past	7	4	1	1	3
Content knowledge	2	4	2	6	2
Training	3	7	3	3	0
Strict scope and sequence	3	6	4	1	2

the following problems on a scale from 1 to 5, with 1 being a major problem and 5 being no problem:

- time
- coordinating of students
- planning for instruction as a team
- coordinating of student assessments
- availability of models and/or materials
- communication
- exposure to correlation in the past
- content knowledge (in one or both disciplines)
- training
- strict scope and sequence

Teachers were also given an opportunity to identify problems that are not on this list; only one teacher opted to add a comment about a lack of administrative support. Based on this response, administrative support will be added to the survey.

The areas identified to be most problematic by the teachers were time, planning for instruction as a team, and exposure to correlation in the past. These problems are inherently addressed by the program. *Mix It Up* incorporates time for teachers to plan lessons, supports teachers planning together in a team, and exposes teachers to correlation in the classroom. Program faculty make the models explicit; they discuss with our teachers the process for writing a correlated lesson, the challenges faced, and the solutions implemented. Therefore, from a programmatic prospective, these problems are addressed.

Teachers reported the fewest concerns about the availability of models and/or materials and content knowledge. These reports are particularly concerning, but again, not surprising. The concern arises from an intuitive notion that a lack of models and content knowledge are the most prevalent problems in middle schools, and these are the most difficult problems to address. This is not surprising because, as noted above, teachers believe they are using correlated models that are actually integrated models. Fewer concerns about the availability of models may be a direct result of the teachers' inability to distinguish between integrated and correlated at the time of the survey. If teachers believe that the materials only needed to use mathematics as a tool in a science lesson or that they only needed to use science applications in a mathematics lesson, then it makes sense that they may perceive an availability of models and/or materials. Are teachers, however, using models and materials that focus on the conceptual nature of teaching two disciplines together with specific objectives from each discipline? Several models and materials supporting integration and elements of correlation exist, but resources accessed by teachers are quite limited.

For example, Berlin (1991) published a bibliography containing 448 citations, where publications range from 1905 to 1991. A second bibliography was published with 402 documents spanning the years 1991 to 2001 (Berlin & Lee, 2003). A majority of these citations are found in journals. The teachers who participate in our program are often unaware of the variety of journals available in their field. Also, many of these articles approach integration from a research perspective. Teachers often find it difficult to identify which articles will be helpful to them and how they can adapt the research-based articles to classroom practice.

The *Mix It Up* program is in the process of building

Table 2
Discriptive Statistics for Quantitative Reasoning

Scale	N	M	SD
Mathematics Pre-test	20	25.70	4.79
Mathematics Post-test	20	27.50	2.80
Science Pre-test	20	12.15	4.73
Science Post-test	20	20.15	3.86

Table 3
Descriptive Statistics for Algebraic Reasoning

Scale	N	M	SD
Mathematics Pre-test	17	12.18	4.14
Mathematics Post-test	17	20.59	5.50
Science Pre-test	17	9.59	2.87
Science Post-test	17	9.88	4.61

a resource library to address this limitation, focusing on cataloguing existing resources to assist teachers in applying research to the classroom. The program provides opportunities for teachers to become members of organizations and subscribe to journals. Program faculty assist teachers in finding resources specific to particular topics. Additionally, program faculty use ideas from the journals in classroom correlated lessons, demonstrating the benefits of using existing resources and connecting theory and practice.

Another alarming result from the collective data is that content knowledge was the problem ranked lowest by teachers. Some teachers may have been unaware of the gaps in their own content expertise (Ma, 1999; Meier et al. 1998). If teachers are unaware of the gaps, will they strive to gain deeper understandings of both mathematics and science concepts? The results from summer 2007 data indicate that conceptual understanding was a primary outcome of the intensive summer sessions. We employed a within subjects (teachers) dependent measures *t*-test to assess the change in content knowledge from pre-test to post-test scores for two of the summer 2007 correlated courses: Quantitative Reasoning and Algebraic Reasoning. Our analytic approach allowed us to model the dependence (i.e., the correlated structure among teacher-level scores within individual classrooms statistically and across time). We found statistically significant results in both mathematics ($t = 2.486$, $p = 0.022$) and science ($t = -7.812$, $p = 0.000$) in the Quantitative Reasoning course, indicating gains in both mathematics and science content knowledge. Cohen's *d*, determined by the pooled standard deviation, was used to determine the effect size. For the mathematics content area, a medium effect was found ($d = 0.5$). As related to the average percentile standing, this places the average of the students taking the post-test in the 69th percentile relative to the average of the students taking the pre-test. A larger effect ($d = 1.9$) was found for the science content area. This effect size places the mean scores in the 97th percentile.

We found statistically significant results in mathematics ($t = -5.281$, $p = 0.000$), but not in science ($t = 0.313$, $p = 0.758$) in the Algebraic Reasoning course. For Algebraic reasoning, Cohen's d determined a large effect size ($d = 1.7$) for mathematics and a small effect size ($d = 0.1$) for science. For the average mathematics scores, the effect size places the mean of post-test scores in the 95th percentile relative to the mean of the pre-test scores. Similarly, the science means were placed in the 7th percentile. It is important to note that since the sample sizes were small ($N = 20$ and $N = 17$) and the scales for the subtests were ordinal and relatively restricted in range, a non parametric analysis was ran in parallel with each standard dependent *t*-test. Non parametric tests produced the same results as the standard *t*-test.

Further support for gains in content knowledge emerged from the teachers' daily reflections and comments in class. Additionally, the teachers commented on how participating in correlated lessons led to the recognition of their own gaps in content knowledge. One of the program evaluators made the following observation: "The daily self-reflections completed by teachers throughout the summer [2006] term suggest

that the correlated lessons were highly effective in confronting teachers with the limitations of their own conceptual understanding and motivating them to develop stronger and deeper conceptual understandings of the content material in both mathematics and science." These are some sample comments from summer 2006 supporting this observation:

"What is motion? We still don't know or do we? Urrgh!" (Day 3)

"Figured out what motion is! Functions are everywhere. Motion is more than just moving." (Day 5)

"I learned that the absolute value represents distance."

"I had never looked at the curvature of a position time graph and seen acceleration before."

"We came up with a mathematically correct procedure for converting units. The lesson in functions was one of the highlights for me because I hadn't learned this before."

"I had never explored Newton's 2nd law so extensively and in relation to energy. I had never made the mental connection with mechanical/chemical/electrical energy to potential/kinetic energy."

"I didn't have the visual understanding of operations as moving forward/backward and negative numbers facing left, positive numbers facing right. Simple lessons, big concept!"

The summer 2007 data also support the notion that content knowledge issues come to light during the program. These are some sample responses from summer 2007:

"The rules behind exponents. I can now see patterns when we multiply lets say same bases with exponents. You add the exponents."

"I learned about trophic levels. I had never heard that word before."

"The differences and similarities between distance and displacement was one thing I learned today."

"I am still in the learning stages on velocity and acceleration."

"I did not know what a prism or a pyramid was describing."

"I learned how to find the mass of irregular objects in science. I also learned what the term density means and how it's derived."

These results are important and relevant to the program since they support the unique aspects of the conceptual nature of the model. Teachers were forced to grapple with the content, look for parallel concepts and misconnections and work out language issues. Since the teachers had to make conceptual connections, they began self-identifying content-knowledge problems. Teachers are recognizing not only areas in which they struggle, but how this impacts and transfers to their classrooms. Here are some samples of teacher comments from both summers 2006 & 2007 supporting the notion that they may be misleading students in some instances of their teaching:

"Through the exploration of various expressions, equations, formulas and functions, I now realize that the way I was taught to solve equations (and evaluate expressions) is not the correct justifiable approach. I realized that although I am teaching my students how to get a solution, I am omitting steps that are crucial to the justification of the process." (summer 2006)

"(I can now see) speed in the way motion is represented graphically plus the importance of transmitting this to students." (summer 2006)

"Even though it was somewhat confusing in the beginning, I learned how to use the number line and matchbox cars to reinforce positive and negative integers with my students. I think that it would require a lot of explanation and making sure they understand the reasons for facing positive or negative, but it would be a great tool in the end." (summer 2006)

"I think the conceptual understanding that I acquired today [was] about ratios, rates and unit rates, so I can come back stronger to my students next school year." (summer 2007)

"I understand the concept well, but explaining it to students is challenging. This lab has potential. It

will be used!" (summer 2007)

"I liked the manipulation of the temperature formulas using mathematics because my students have difficulty understanding how the temperature scales." (summer 2007)

In conclusion, teachers clearly identify a need for correlation in their classrooms and see the benefits with their students. And although teachers may have difficulties initially understanding the difference between integrating and correlating, the experiences of an intense summer program that models correlation supports the teachers' progression from integration to the conceptualization of correlation. Through this investigation, it was found that that (1) teachers identify planning time, planning with other teachers, and exposure to correlation in the past as problems they encounter with correlating, which is addressed in the *Mix It Up* program and (2) teachers do not necessarily recognize problems with content until they experience conceptual-based teaching and learning through collaborative correlated models. These results regarding teachers' beliefs about the value of correlating and the problems teachers encounter with correlating can be used to expand the efforts of the *Mix It Up* program to help teachers understand the limitations of correlation and gain strategies for overcoming these limitations.

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Mathematics and Science Integration: Models and Characterizations

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The squeeze on instructional time and other factors increasingly leads educators to consider mathematics and science integration in an effort to be more efficient and effective. Unfortunately, the need for common understandings for what it means to integrate these disciplines, as well as the need for improving disciplinary knowledge, appears to continue to be significant obstacles to an integrated approach to instruction. In this study we report the results of a survey containing six instructional scenarios administered to thirty-three middle grades science and math teachers. Analysis of teacher responses revealed that while teachers applied similar criteria in their reasoning, they did not possess common characterizations for integration. Furthermore, analysis suggested that content knowledge serves as a barrier to recognizing integrated examples. Implications for professional development planners include the need to develop and provide teachers with constructs and parameters for what constitutes mathematics and science integration. Continued emphasis on improving teacher content knowledge in both mathematics and science is also a prerequisite to enabling teachers to integrate content.

The call for making purposeful connections across various academic disciplines is nothing new or exceptional. Most subject area teacher organizations agree that there is value in and a need for interdisciplinary instructional approaches (National Council for the Social Studies, 1994; National Council of Teachers of English, 2000; National Council of Teachers of Mathematics, 2000; National Science Teachers Association, 1996). Collectively, these organizations have met to establish guidelines for integration and some have even insisted that school schedules be adjusted to increase opportunities for content integration. The National Research Council's book *How people learn: Brain, mind, experience, and school* (Bransford, Brown, & Cocking, 2000) supports a shift away from traditional curricula and toward those that assist in "the development of integrated knowledge structures" (p. 139) as an important component in improving learning environments.

The evidence in support of an integrated approach is mixed. George (1996) identified at least thirteen unsubstantiated benefits typically claimed for integrated instruction including increased opportunities for problem solving, greater knowledge retention, and greater student involvement with curriculum planning. A literature review by St. Clair and Hough (1992) of prior studies regarding the efficacy of curriculum integration did not show this practice to be any more effective than traditional instruction and suggested the need for additional studies yet little has been done since then. Conversely, there are other studies that have shown integrated instruction to have a positive impact on student achievement scores (Greene, 1991; Stevenson & Carr, 1993; Vars, 1991). Narrowing the focus on two specific disciplines may make questions regarding evidence and method(s) for integration less complex to address.

Integrating mathematics and science may be the "low hanging fruit" for content integration. There is a long history of efforts to link these two disciplines (Berlin & Hyonyong, 2005); the two disciplines are typically viewed as logically connected (American Association for the Advancement of Science, 1990; McBride & Silverman, 1991; Pang & Good, 2000;). Furthermore, some studies have shown that integrating mathematics and science has a positive impact on student attitudes and interest in school (Bragow, Gragow & Smith, 1995; McComas, 1993) motivation to learn (Guthrie, Wigfield & VonSecker, 2000), and achievement (Hurley, 2001). In their literature review of mathematics and science integration, Czerniak, Weber, Sandmann and Ahern (1999) cite numerous anecdotal reports providing support for integration but perhaps more troubling they also found an absence of any consistent operational definition for integration. These findings echo findings from earlier studies (Berlin & White, 1992; Davison, Miller, & Metheny, 1995; Lederman & Niess, 1997) regarding the need for defining mathematics and science integration. Collectively, these researchers report on the variety of continua and models of mathematics and science integration based

on what is being integrated (e.g., content, processes), structures for integration (e.g., themes, projects, techniques) and degrees of integration (e.g., separate content of disciplines versus seamlessness, dominance of one discipline over the other versus equivalence). More recently Hurley (2001) provided some quantitative evidence in support of an integrated instructional approach for mathematics and science in her review of 31 studies employing this strategy but, as previously with Czerniak et al. (1999), also found that multiple forms of integration were being implemented.

There are other significant challenges to implementing integrated instruction. Researchers have identified such concerns as classroom management issues, utilization of integrated instructional materials, teacher content knowledge gaps, and time constraints (Frykholm & Glasson, 2005; McBride & Silverman, 1991; Meier, Nicol, & Cobbs, 1998; Van Driel, Beijaard, & Verloop, 2001). These concerns are real yet not insurmountable because improving teacher content knowledge, instructional materials and classroom management are frequent targets for professional development experiences albeit mathematics and science integration are not typically the context for those experiences.

The positive yet somewhat anemic evidence for integration is modulated by the lack of a common understanding of what it means to integrate content. The unequivocal appeal for defining mathematics and science integration is both reasonable and is a necessary precursor to truly gauging the efficacy of this practice. The current study was designed to probe further to learn more from teachers about the kinds of instructional examples teachers think reflect integration as well as how teachers tend to characterize integration. Using this information, well-designed professional development experiences should then involve the task of developing parameters for implementing mathematics and science integration. Establishing these parameters would appear to require learning more about teachers' content knowledge in both subject areas and how they define and characterize integration. Gathering these data should lead to the construction of a professional development framework designed to address these tasks and support teachers in their efforts to integrate mathematics and science.

Examples and Characterizations of Integration

The study described here builds from a 2006 pilot survey to explore science teachers' knowledge of mathematics concepts and skills. Eighth grade science teachers were given a list of selected 8th grade state standards for mathematics and asked to indicate the degree to which they understood and could integrate them into science standards they addressed with their students. Results from that early survey revealed it was common for teachers to be unsure about the meaning of some of these mathematics concepts and skills and that they had difficulty envisioning how some mathematics concepts and skills could be integrated with the science they taught; this was particularly true with regard to geometry. This prior study confirmed that while the idea of content integration might be intuitive, effectuating content integration in classrooms may not be as straight-forward as it seems.

In the current study, middle grades science and mathematics teachers were surveyed to explore their understandings about mathematics and science integration. Teachers were asked to reflect on scenarios describing integrated mathematics and science lessons as well as provide their own examples of lessons they had taught in an integrated fashion. Each scenario loosely mirrored one of the five types of mathematics and science integration models identified by Davison et al. (1995): discipline, content, process, methodological and thematic. No attempt was made to develop scenarios specifically matching each model since we were more interested in participant characterizations of integration as opposed to precise definitions.

In this study, our research questions were:

- What examples of mathematics and science teaching do teachers in grades five to eight identify as integrated?
- How do these teachers characterize integrated mathematics and science teaching?

Findings from this current study may help inform professional development providers as they attempt to determine teachers' existing conceptions of integration by using different mathematics and science integration models. Professional development offerings can then include opportunities to build on integration models teachers already know and use and focus on other models in order to encourage teachers to try them.

Method and Analysis

In order to answer these research questions, we designed an open-ended survey based on a modified version of Hewson and Hewson's (1989) *Conceptions of Teaching Biology*. This survey provided respondents with short descriptions of teaching scenarios and then asked teachers:

a) Is this an example of …
b) If yes, how can you tell …

If no, what would/could you change to make this an example of …

This survey and an introductory letter was sent to 41 principals at area middle schools and asked if they would:

> distribute surveys, consent forms, and envelopes to **5** randomly selected teachers (who work with students in **grades 5-8**) and teach **mathematics or science**? These teachers could be either subject specialists who only teach mathematics or science or multi-subject specialists who teach all subjects in contained classrooms.

We received 33 surveys via mail from teachers. The survey was titled *Defining Mathematics and Science Integration*. On the first page the directions were as follows:

> Please read the 6 scenarios below. For each, circle *yes* if you feel this is an example of integrated teaching or *no* if you feel this is not an example of integrated teaching. Based on your "yes" or "no" response complete the appropriate question that follows to further develop your response.

We first analyzed the survey data by tallying responses. We focused on each scenario individually and counted the number of "yes" responses and the number of "no" responses. This gave us an idea of which scenarios teachers felt were most indicative of integration and which were not.

Next, we analyzed the teachers' written responses using a qualitative methodology. During the first stage of analytic induction, we independently read all 33 of the surveys and focused on each of the six scenarios for a "general sense of the whole" (Patton, 2002). Themes emerged as descriptions of which scenarios the teachers perceived as examples of integration and why they felt these scenarios were examples of integration. These themes emerged "out of the data rather than being imposed on them prior to data collection and analysis" (Patton, 1990, p. 390).

After establishing these themes, we reanalyzed the surveys but framed this second analysis around creating what we felt was a definition of integration for each teacher. In other words we started with, "Teacher #1 defines integration as ___," created a spreadsheet to list these definitions, and did this for all 33 teachers. The research team did this individually and then met to talk about our spreadsheet definitions for each teacher. Based on this analysis we created five definitions that we felt delineated the ways in which the teachers characterized integration. Finally we clustered the teachers' characterizations into each of these five definitions.

After researcher meetings and discussions, we attempted to describe how the teachers' definitions of integration impacted their decisions about whether or not the scenarios were examples of integration. These procedures correspond to a "grounded theory" approach (Glaser & Strauss, 1967).

Findings

Examples of Integration

As mentioned previously, the six scenarios used in this study were designed, in broad strokes, to mirror some of the different models of mathematics and science integration. Davison, Miller and Metheny (1995) identified five types of mathematics and science integration: discipline, content, process, methodological and thematic. Prior to analysis of individual responses and grouping them, it was useful to explore the general impression they had of each scenario. In that vein we believed that process, content and discipline models of integration tend to make conspicuous the facts, concepts, processes and skills involved by placing them in the foreground of the scenario or activity. Furthermore, perceived that content in these models may tend to resonate with teaching experiences and knowledge fairly common to teachers. Scenarios where the content was more explicit and familiar were identified as "typical" scenarios (Figure 1 below). Similarly, we perceived that thematic and methodological integration tend to place specific facts, concepts, processes and skills in the background since these may be combined or embedded at different levels of complexity depending upon the nature of the task or activity. These models tend to be less explicit in identifying content and present relatively novel activities or applications. Therefore, we identified scenarios where the content was less explicit and familiar as "atypical" scenarios (Table 1 below).

Our "typical" and "atypical" designations proved to be somewhat useful. As seen in Table 1, larger percentages of participants found "typical" scenarios to be integrated examples.

Scenario E was overwhelmingly identified as an example of integrated teaching (87% of teachers said "yes"). This scenario clearly identified a context (the solar system) and content (facts about celestial objects,

Table 1
Survey Scenarios and Integration Models

Scenario	Content	Participants Identifying Scenario as Integrated	Survey Question
A	Typical	68%	Students in seventh grade mathematics are working on graphing data. The teacher has student pairs measure their pulse each minute for ten minutes while one student jogs in place.
B	Atypical	53%	Sixth grade students are studying a unit on earthquakes. The teacher asks students to find the difference between two historical earthquakes using a table involving magnitudes according to the Richter scale.
C	Typical	72%	A fourth grade class is doing a project on dinosaurs. A group of students makes a chart that compares the sizes of the 5 different dinosaurs showing their metric heights and weights.
D	Typical	69%	Students are investigating ocean floor depths using data from sonar equipment. They are given the equation: $D = \frac{1}{2} T \times V$ Where D = depth in m, T = time in s, V = the speed of sound in water (1534 m/s) Students are then asked to compute ocean floor depths given the time required for sound to be sent and return to an echo sounder.
E	Typical	87%	During a unit on the solar system, the teacher asks the students to create a scale model that shows the relative size and distance between the Earth and two other planets.
F	Atypical	60%	Eighth grade students are investigating crystal formation as the liquid in different solutions evaporates. Students are asked to observe and describe various characteristics of the crystals formed when the rates of evaporation, solutes used and container shape are manipulated.

creation of a scale model) and presented a clear connection between the two disciplines. For those who indicated this was not an example of integration, there was no apparent pattern of reasoning and some comments appeared to reflect a misunderstanding of what was meant by "scale model". One teacher suggested that the model would be "too small" for students to benefit from it while another reflected that this scenario might show how "math and architecture" go together.

In a similar vein as the previous scenario, Scenario C was gauged by most teachers to be an example of integration (72%). Again, the context (dinosaurs) and content (facts about various dinosaur heights and weights, creation of a chart for comparisons) was sufficient to convince the majority of teachers that elements of both disciplines were evident. Interestingly, although the science content in this scenario involved a project on dinosaurs, no respondent overtly questioned the fact that a study of dinosaurs had no connection, per se, to state or national science standards. Perhaps objections to dinosaurs as an appropriate science topic were captured by teachers in other ways. When prompted for ways to make the scenario more integrated, several teachers suggested expanding on concepts related to dinosaurs (e.g., diet, body features, evolution) while others chose to focus on "beefing up" the mathematics (e.g., performing metric conversions, using proportions, graphing data). A few teachers overlooked the scenario's reference to fourth grade students and indicated this activity would not be sufficiently rigorous for the upper grade level they taught.

Scenario D was identified by 69% of teachers as an example of integration and the content (ocean floor depths, computation) clearly identified disciplinary aspects for most but, compared with previous scenarios, a larger percentage of teachers found this item lacking. Teachers indicating this item was not integrated described the need to pay more attention to science con-

tent (e.g., ocean floor life, ocean floor features, how sound waves travel) and were dissatisfied with the rigor of the mathematics (computing distance given speed and time data).

Scenario A described an activity where students measure their pulse as they exercise and then graph the data. While 68% of teachers agreed this scenario was an example of integration, the majority of teachers, even those who agreed it was an integrated example, wanted more contextual detail and more attention to content. Teachers wanted explicit references to the link between physical activity and pulse rate and some wanted more detail on how data were to be graphed. Additionally, a frequent comment from teachers regarded the need to know more about antecedent events and subsequent instruction to assure integration was occurring. This item was unique because some teachers identified the topic of pulse rate as an issue for "health class" and not science which would eliminate this scenario as an example of science and mathematics integration for these teachers.

Only 60% of teachers identified the scenario exploring evaporation and crystal formation, Scenario F as integration. Arguably, this scenario identified a rich context (evaporation of liquids and crystal formation) and array of content (investigating relationships between solutes, container shapes, or evaporation rates and crystal size or shape) that could require students to apply knowledge and skills from multiple domains. The science was apparently in evidence; however, the lack of specifically identified skills and processes in mathematics caused many teachers some concern. Based on results from the 2006 pilot survey mentioned earlier in this paper, the difficulty teachers had in seeing this scenario as an example of integration could be attributable to the mathematics content. Teachers to the 2006 pilot survey overwhelmingly rated concepts within the geometry standard as least familiar to them or most difficult to integrate with science. Perhaps the reactions to geometry concepts and to integration scenarios involving geometry reflect a larger issue regarding the need to improve teacher content knowledge in geometry.

Scenario B was identified as integration by only 53% of teachers. While the context (earthquakes) and content (interpreting a table and comparing numerical values with observations) are identified, teachers who indicated that this was not integration wanted clearly recognizable mathematics skills and processes listed in order to make it integrated. In fact, the relatively consistent reactions to all of these scenarios involved the need for recognizable content from both disciplines as the sine qua non for integration. Teachers generally appeared dissatisfied with scenarios that might present rich opportunities to integrate content but did not specifically name concepts and skills from both disciplines.

Teachers' Characterizations of Integration

Following analysis of item responses, survey responses were individually analyzed in an effort to

Table 2
Teachers' Characterizations of Integration

Description	Participants	Notes
Topic checks and balace	6, 11, 12, 13, 17, 24, 25, 26, 27, 32	Teacher looks for topics that she/he can match to math and science disciplines. 6 and 13 may not recognize content to confidently identify scenario as integrated[a].
Missing piece (required)	1, 4, 8, 9, 10, 15, 21, 29	Scenario needs explicit reference to specific content/topic (Richter scale) or skill (graphing) to make scenario acceptable and add desired context.
Make it richer	5, 7, 14, 16, 18, 22, 23, 28, 30, 33	Scenario needs broader scope than what's described. Goes beyond focus of scenario.
I know students	20, 31	Teacher seems to reflect on his/her own experience and identifies skills (largely math) that require attention
Yes, if instruction is right	2, 3, 19	Needs instructional details of scenario. Overlaps with Missing piece

Note. [a]Comments from participants 6 (e.g., scale too small on scenario 5) and 13 (e.g., volume changing with container shape) indicated either serious misunderstanding of the several scenarios or the underlying scenario content.

group teachers according to their characterizations of integration. Table 2 represents the descriptions which categorize teachers' characterizations.

Topics checks and balances: At the most basic level, teachers who characterized integration in this way identified a mathematics topic and a science topic as their evidence for integration. About 27% of these teachers found sufficient evidence of mathematics and science content to identify every scenario as an example of integration. When prompted to provide personal instructional examples of integration in their classrooms, these teachers wrote about using Punnett Squares (science), probability (mathematics), Laws of Motion (science), and performing calculations using related mathematical formulas, to name a few. Teachers apparently viewed recognizable mathematics and science topics as necessary but not necessarily sufficient assurance that these disciplines are being integrated.

Missing piece: Some teachers determined that an essential concept or skill was missing from the scenario. In reacting to the scenarios, they indicated additional science content (e.g., explicit references to instruction about the Richter scale, comparing pulse rates of students resting with those who are exercising, how sound waves travel) or mathematics (e.g., calculating percentages, graphing data, performing metric conversions) would have shifted the scenario into the integrated category. In their personal instructional examples of integration, some teachers felt compelled to provide detailed examples of traits they might study (widow's peak, handedness, tongue rolling, etc.) and applications of mathematics (use of bar graphs or Venn diagrams to display data) involved with studies of dominate and recessive traits. In these instances it appeared as if integration hinged on a more complete listing of mathematics and science concepts or skills addressed.

Make it richer: Some teachers' characterizations focus on the need to significantly enrich the scenario beyond the limited scope described. They appeared to prefer scenarios that reflected a broader range of topics and opportunities to link concepts together. For example, instead of merely calculating ocean depths, a more integrated approach would include "ocean floor flora and fauna." In addition to examining the impact of exercise on pulse rate, the scenario should have included references to the pulse rate differences between fit and unfit students. Their personal instructional examples of integration included references to a unit on sound that was extended to address Alexander Graham Bell and art.

I know students: Another distinction among grouping of teachers concerned a focus beyond mere listings of the content to be addressed. For these teachers, knowledge of how the activities and content were related to "real life" was important. Their personal classroom integration examples included a reference to a Crime Scene Investigation (CSI) activity and an activity where data from home were gathered. Consistently these teachers wanted evidence of the practical value and application of the scenario. Evidence for integration depended on the authenticity and usefulness of what students were doing.

Yes, if instruction is right: A final category of teachers was similarly less concerned about content and more interested in instructional details. These teachers wanted to know more about what was taught prior to the scenario described or more about the nature of the discussions that they insisted would need to take place after the activity described in each scenario. Their personal integration examples included references to the process the teacher used in teaching students to graph. For these individuals, what transpired before and after each scenario was apparently pivotal in determining whether or not integration had taken place.

Interestingly, two of the teachers in this investigation were unable to identify any of these scenarios as an example of mathematics and science integration. One teacher was characterized as *Make it richer* due to his/her insistence of requiring additional topics and applications be included for every scenario. The second teacher was characterized as *I know students* due to his/her references to instructions and content that he/she deemed prerequisite for each scenario. This teacher identified what he/she would do "first" in response to every scenario as well as in his/her personal instructional example of integration. Finally, 22% of these teachers judged half of the scenarios to be integrated and the half not integrated. Within this group, split decisions were reflected on every scenario except Scenario 5 (solar system) which they all agreed was integrated and Scenario 2 (earthquakes) which they all agreed was not integrated.

Discussion

Our first research question concerned identifying examples of integrated mathematics and science teaching. Analysis of teacher responses to each scenario in this study in conjunction with their personal examples of integrated lessons from their classrooms provided a better sense of the criteria teachers apply in recognizing

mathematics and science integration. Scenarios that contained content and activities that were arguably more common (i.e., solar system, graphing) tended to be identified more frequently as integrated. Scenarios that were less explicitly in conveying content or activities (i.e., investigating crystal formation, studying historical earthquakes) tended to be identified as not integrated. Our second research question dealt with how middle grades teachers characterized integrated mathematics and science teaching. To a significant extent, teachers' primary criterion for integration focused on the presence or absence of content and skills they deemed essential. However, in a variety of instances teacher responses signaled either a misunderstanding of the scenario or of the underlying content. For example, one teacher suggested graphing energy use of household appliances in response to the pulse rate scenario while another, in scenario three suggested having students,

> compare trees around their neighborhood to their height. Then use the dinosaur height to estimate how high trees would be if there was a proportional relationship. Then students can make an argument as to where dinosaurs could live if they weren't extinct.

Questionable content knowledge or understanding of the scenario certainly flavors teachers' abilities to discern when integration is taking place. While none of the teachers in this study identified weak or dubious content knowledge as a source of difficulty in gauging integration, some of the comments strongly suggest this is an issue. Having deeper disciplinary knowledge seems to be, for some teachers, a barrier to an interdisciplinary approach.

The instructional context for the scenario was the second significant criterion of concern for teachers in this study. Teacher comments included concerns about instruction that should take place prior to the scenario (e.g., "teach how to find differences first"), instructions students are given during the scenario (e.g., "relationships between force and magnitude are not explicitly discussed") or activities that may follow from the scenario (e.g., "it depends on what students do with the data"). With one exception, teachers explicitly applying this criterion did not focus on the instructional context in every scenario. This may suggest that they may have found the listed content and skills in other scenarios to be acceptable to qualify as integration making instructional context a less important criterion for integration. One teacher did apply this criterion consistently and included what she/he would do "first" in response to every scenario. This teacher may have difficulty in identifying any scenario as integrated unless it conforms to his/her sense of some sequence or context he/she deems essential.

Ultimately, this study reinforces the need to provide teachers with a clearer understanding of what mathematics and science integration is and is not. In the absence of clear characterizations or parameters for what constitutes integration, teachers apply their own criteria based upon their knowledge and beliefs. After examining the content and skills identified in each scenario, teachers appeared to compare these with their own content knowledge. A second layer of scrutiny involved comparisons between scenarios and their own classroom experiences. Unless teacher content knowledge and classroom practice is generally where the science and mathematics education community would like it to be, science and mathematics integration is likely to be ill-defined and ill-practiced.

Conclusion

Although one limitation of this study is the sample size, the implications support the suggestions made by other researchers: if mathematics and science integration is a desired practice in schools then teachers must have a strong sense of what it means to make this happen. Potential gains from integration (i.e., time savings, improving student achievement, improving student interest or motivation) are predicated on a common understanding for what integration means. At the very least, curricula or initiatives designed to foster integration must develop operational definitions for integration before laying claims to an integrated approach or product. Professional development for teachers where science and mathematics integration is a desired outcome must begin by providing teachers with a sense of how teachers will know integration when they see it.

This study also points to the ongoing concern of teacher content knowledge. Teachers of science may generally be in need of science content knowledge improvement just as teachers of mathematics may be. However, once we ask teachers of science to recognize and understand connections to mathematics and vice versa, we create new knowledge gaps and challenges. Professional development for mathematics teachers, for example, may need to "shore up" their mathematics content knowledge while simultaneously introducing them to new concepts and ideas from science disci-

plines.

Finally, professional development designers and providers should find these results informative and the survey instrument useful. Professional development experiences focused on integrating mathematics and science should involve attention to strategies and tools that may uncover teacher perceptions of what it means to integrate these disciplines. The survey tool used here may form the basis for delving deeper into teacher conceptions and characterizations of integration in an effort to determine if content knowledge or instructional context serve as more significant barriers to implementation. Professional development designers can then make better use of teachers' current understandings and purposefully target those content or context concerns.

As a result of this study, we identified several facets to mathematics and science integration that represent interesting possibilities for future investigations. Foremost among these is an exploration into the connection between teacher perceptions of their own content knowledge and their ability to identify mathematics and science content to integrate. Inflated perceptions of their own knowledge may place many rich topics and concepts out of consideration for integration. Additionally, in conjunction with characterizing mathematics and science integration, future studies should continue to explore the potential benefits to this practice. Teachers may be more likely to implement practices they understand and value.

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Scientists' Perspective on Introducing Authentic Inquiry to High School Teachers During an Intensive Three-Week Summer Professional Development Experience

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The Information Technology in Science (ITS) Center for Teaching and Learning was a National Science Foundation funded program to provide high-quality professional development for 7-12th grade science teachers. The subgroup on which this paper focuses was immersed in an innovative approach to understanding chemistry of the environment. The group was comprised of 10 high school science teachers representative of science classes taught at all grade levels (9-12th). A team of four university professors led the group. The professors developed inquiry modules and communicated some of the intricacies of their research for adaptation to the participants' classrooms. This paper communicates the successful implementation and lessons learned by scientists during the course of an inquiry-based curriculum during summer 2005. The process and pace at which the material was covered, qualitative information about the attitudes of the participants towards the curriculum, and implications for professional development from the point of view of the science team leaders will be discussed. Analysis of time spent with participants revealed the progression and type of activities chosen for the professional development experience were effective. Results from informal participant interviews revealed they were most comfortable in incorporating inquiry into their classrooms after having been immersed in it themselves.

One of the goals the National Science Standards has set for all students of K-12 education is that as they progress through school they should "understand more science concepts and processes and their explanations should become more sophisticated…frequently reflecting a rich scientific knowledge base, evidence of logic, higher levels of analysis, and greater tolerance of criticism and uncertainty" (National Academy of Sciences [NAS], 1995, p. 115). Upon completion of the 12th grade, students should have the ability to assess concepts about the world, understand the motivation for undertaking research, and be able to critically analyze scientific results (NAS). One way for students to achieve these standards is for teachers to understand and be able to create an authentic inquiry experience for their students.

In differentiating authentic inquiry from traditional inquiry, one must examine the relationship to between the task(s) the students are asked to complete and the approach a scientist would take in conducting their own research. The working definition of authentic inquiry, as explained by Chinn and Malhotra (2002) and used throughout this paper, is characterized by encouraging students to explore concepts from many different perspectives, using multiple sets of data to prove concepts, and to learn how to analyze and evaluate proposed procedures and solutions.

There are many stages in achieving authentic inquiry within the Chinn and Malhotra (2002) framework. The first stage involves the participants' ability to generate their own researchable questions. The next stage involves participants designing their experimental procedures. Authenticity of their inquiry is established by their ability to select appropriate variables, develop complex procedures, and make numerous measurements to create reliability and accuracy within their experiments. Authentic Inquiry also engages the participants in examining possible errors within their experimentation, observation, and analysis. During the analysis, participants are asked to make generalizations and engage in many types of reasoning before reaching their conclusions. At the end of the inquiry, participants are asked to develop theories and support their results from the combination of multiple studies.

An additional difficulty in achieving these goals throughout the K-12 education system is that the student population is becoming increasingly diverse; while the teachers, administration, and curriculum have not reflected this change (Greenwood & North, 1999; National Science Foundation [NSF], 2001). The National Science Foundation (2001) reported approximately 50% of science and mathematics teachers from grades 7-12 have neither a major nor minor within the field they are teaching. To make matters worse, many teachers with appropriate content training are leaving the teaching profession within the first five years (NSF). Recent reports, however, have demonstrated the positive impact of combining high-quality professional development, for both in-service and pre-service teachers, with standards-based curriculum (NSF). Through the development of the ITS center in-service teachers are immersed in a research-rich learning environment in which they interact with science and education researchers in an intense three-week training program during two consecutive summers. This interaction will enable teachers to bring authentic inquiry experiences back to their classroom, which will encourage the engagement of the increasingly diverse student population. This paper will focus on the development, implementation, and assessment of an authentic inquiry experience during the first summer session.

ITS: Goals and Composition

The goals of the ITS center were (1) to provide a research-rich environment for 7-12th grade teachers to develop expertise in technology and the assessment of science taught with visualization and image technology, (2) to develop strategies and resources to increase the application of technology to teaching and understanding science, (3) to encourage understanding of the way scientist use information technology to answer questions during the course of scientific research, and (4) to conduct basic research on the effectiveness of the application of information technology on the teaching and learning of science (http://its.tamu.edu/). A guiding principle for all teams throughout the ITS center was to address the impact of information technology on scientific and educational research and how it can aid in science education.

One of the five teams involved in ITS, entitled the Molecular View of the Environment (MVE) Team, chose the chemistry of the air, land and water as contexts for implementing technology and inquiry in the high school chemistry curriculum. The team comprised of four professors; one geochemist and three chemists; who organized their activities to bring "authentic inquiry" to the participants using principles that are covered in the participants' curriculum *and* adaptable to their classroom environments. One additional and expressed goal of the MVE Team was to reinforce basic principles and add relevant examples to the existing curriculum without propagating scientific misconceptions. The basic principles were decided upon by aligning the course content to the state standards found in the Texas Essential Knowledge and Skills (Texas Education Agency, 2007). The MVE team tried to incorporate authentic inquiry through the development of in-class laboratory exercises that challenged the participants' thinking and problem solving.

High school teacher participants. The participating high school teachers are selected through an application process. The application process includes evaluation of the applicant's leadership activities, science content background, and interest in pursuing a graduate degree in education or a content area. Participants were accepted based on their potential not only for bringing current science research back to their own classrooms, but also for supporting other teachers in integrating this science into their classrooms. The participants were assigned to a team based on a ranking of preferences they provide in their application package. The participants in Cohort III represented the majority of science subjects taught at the high school level including Biology, Chemistry, Physics, Astronomy, and Integrated Physics and Chemistry (IPC). The participants were also representative of all academic levels of teaching including regular, pre-Advanced Placement, and Advanced Placement. One participant had experience teaching mathematics for students with special needs. All of the participants expressed a desire to increase their knowledge of information technology (IT), chemistry and to bring new ideas and activities back to their schools. Many of the participants also would like to revamp and invigorate the existing laboratory exercises they are currently using.

Science faculty. The science team leaders were recruited through university-wide seminars and follow-up personal interviews with the Center Director. Science team leaders had to be scientists interested in pedagogy, active in interdisciplinary research, and willing to share their current research methodologies and data sets with the ITS participants. The faculty members from Texas A&M University comprising the MVE team were Dr. Ethan Grossman, Dr. Steve Miller, Dr.

Simon North, and Dr. Eric Simanek. The team leaders were recruited by Dr. Simanek based on three criteria. First, all were recognized to be "good teachers" at the undergraduate and/or graduate level. Second, all maintain vigorous research programs that have environmental relevance. Third, all uphold a broader interest in improving science education in Texas.

The outline of curriculum detailed in this paper evolved from an initial summer experience with a previous group of participants within the ITS center. During the course of their first implementation, the faculty found their traditional approach to classroom lecture and activities were not well-suited to advancing the participants abilities in implementing the national standards within their classrooms. The faculty struggled to maintain interest and engage the participants in authentic inquiry and critical thinking experiences. The results of informal participant interviews and additional training into the nature of authentic inquiry resulted in the current curriculum presented in this paper.

Each faculty member presented a three-day module related to the specific faculty member's research interest while stressing the principles covered in the high school classroom. The first module was led by Dr. North and built towards modeling regional air quality and the ozone hole. Dr. Simanek followed with discussions of simple and complex equilibrium with relevance to herbicide fates and drug delivery. Dr. Grossman led module three which focused on the chemistry of natural waters, especially ground waters. Lastly, Dr. Miller presented information on the uses of catalysis and polymer chemistry using the principles of Green Chemistry.

MVE Team Resource Person. Mrs. Laura Ruebush, a graduate student in chemistry education, joined the MVE team as a resource person. Initially, Mrs. Ruebush ordered and organized materials required before the summer session commenced. During the session, she observed how participants responded to the different pedagogies employed by the scientists, assisted participants during the inquiry exercises, and helped participants clarify the relationship between the science concepts in their instructional frameworks (IF) and the science content being taught in the mornings.

Education faculty and teaching assistants. In the afternoon, the participants moved as a group to work on their inquiry-based experiment IF with their education team. The education team leaders are referred to as Campus Resource Persons (CRP). The CRPs working with MVE were Ms. Crista Force and Mrs. Heather Miller, graduate students in the College of Education and the College of Geosciences, respectively. Their role was to aid the participants in understanding the current inquiry literature, to assist in overcoming any challenges that arose during the planning of the participants' IF, and help to facilitate the communication of the inquiry they were trying to implement.

Methodology

The method in which the data were collected followed most closely with that of naturalistic observation. Mrs. Ruebush kept track of the time spent on different modes of teaching, and took snapshots of the classroom every 5-10 minutes or whenever a question was asked by one of the participants. The data collected consisted of interpretation of the participants' responses to the material being presented, the manner in which the material was delivered, and informal personal and group interviews about the participants' feelings on the direction of the course material. Mrs. Ruebush monitored how each faculty member utilized their time in lecture, including such aspects as lecture style, information technology instruction and exercises, and authentic inquiry.

A Prototypical Morning Session

Morning sessions started with a daily pre-test to engage the participants in the day's lecture topic, followed by a late breakfast break. The pre-tests were completed in 5-10 minutes. A sample question from each pre-test given in each module appears in Table 1.

The remaining 2-2 ½ hours of the mornings were typically spent on activities, lecture material, and the use of information technology (primarily Microsoft Excel) to explore the topic. A detailed description of the pace and nature of the curriculum for each module is given in the following sections.

Module 1-Chemistry of the Atmosphere with Dr. Simon North

Day 1: Dr. North started the summer session on *Day 1* with an authentic inquiry exercise using the Black Box experiment (Figure 1), based on the work of Cartier (2000). The purpose of this inquiry was to show the complexity of the nature of science and of scientific models.

The black box measures approximately 1 ft wide × 1 ft deep × 2 ft high and was closed so as to only expose the inlet funnel and outlet spigot. The box has a funnel in the top and one spigot on the side. When water was poured into a funnel in the top of the box, nothing happened… initially. Additional water ulti-

Table 1

Example of Representative Pre-test Questions for Each Module

Module	Chemical Kinetics Atmospheric Chemistry (Dr. North)	Chemical Equilibrium Pesticides (Dr. Simanek)	Natural Water Chemistry Geochemistry (Dr. Grossman)	Catalysis and Polymers Green Chemistry (Dr. Miller)
Questions	Provide one or more examples of scientific models as they apply to atmospheric chemistry.	Give examples of when we worry about equilibrium in everyday life.	Where would you expect to find the purest drinking water (least dissolved salts) and why?	1. The cost of chemical waste disposal in the U.S. is enough to run the state economy of: A. Wyoming B. Wyoming and Texas C. California D. no one state

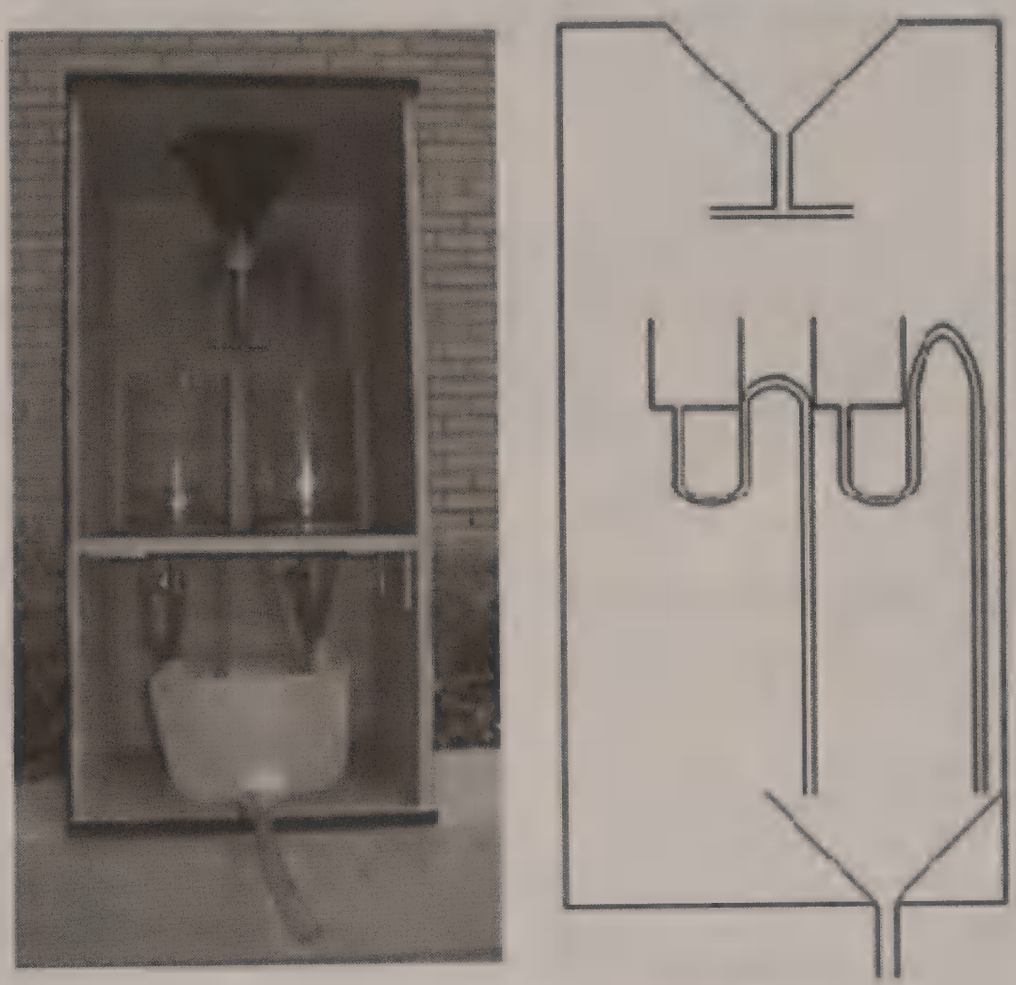

Figure 1. Inside the Black Box. Left-actual picture of the inside of the box. Right-schematic drawing of the inside of the box.

mately produced intermittent streams from the spigot. The participants were told to record water input versus water output, and then hypothesize about what was inside the box. Lecture and discussion focused on the nature of scientific inquiry and modeling.

Day 2 focused on modeling the consecutive reaction (A→B→C). To gain insight into the concept of rate-limiting steps and the steady-state approximation, water was poured into the top of a three-chamber cylinder (with chambers labeled A, B and C, respectively) (Figure 2). The chambers were divided such that the barrier between A and B had a larger hole than the barrier between B and C, making the latter a rate-determining step as water accumulated in chamber C. A

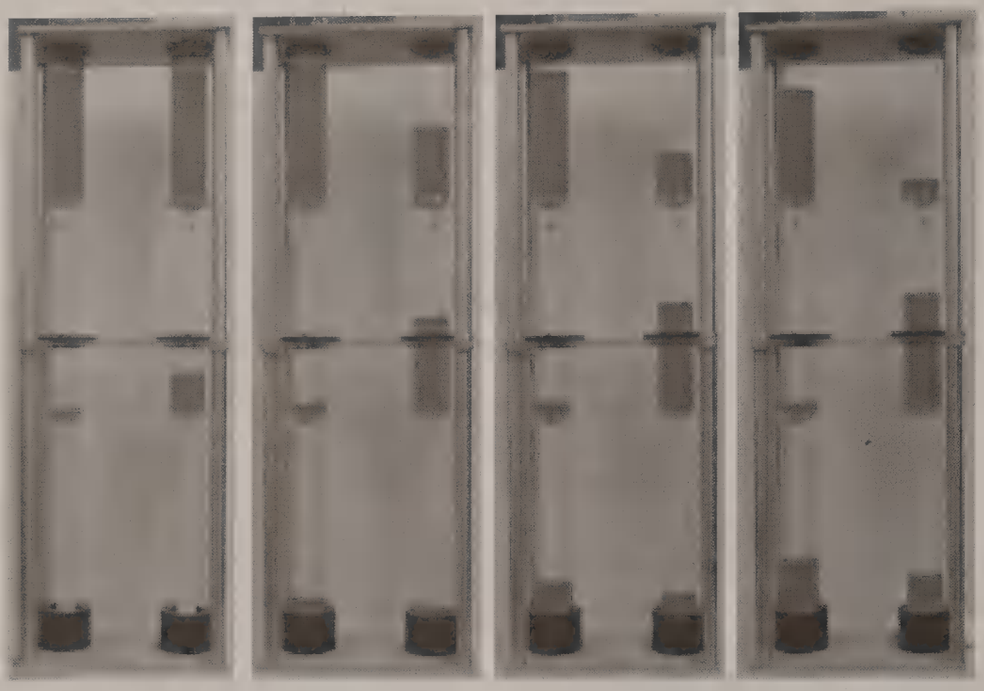

Figure 2. Time-lapse image of the two limiting cases.

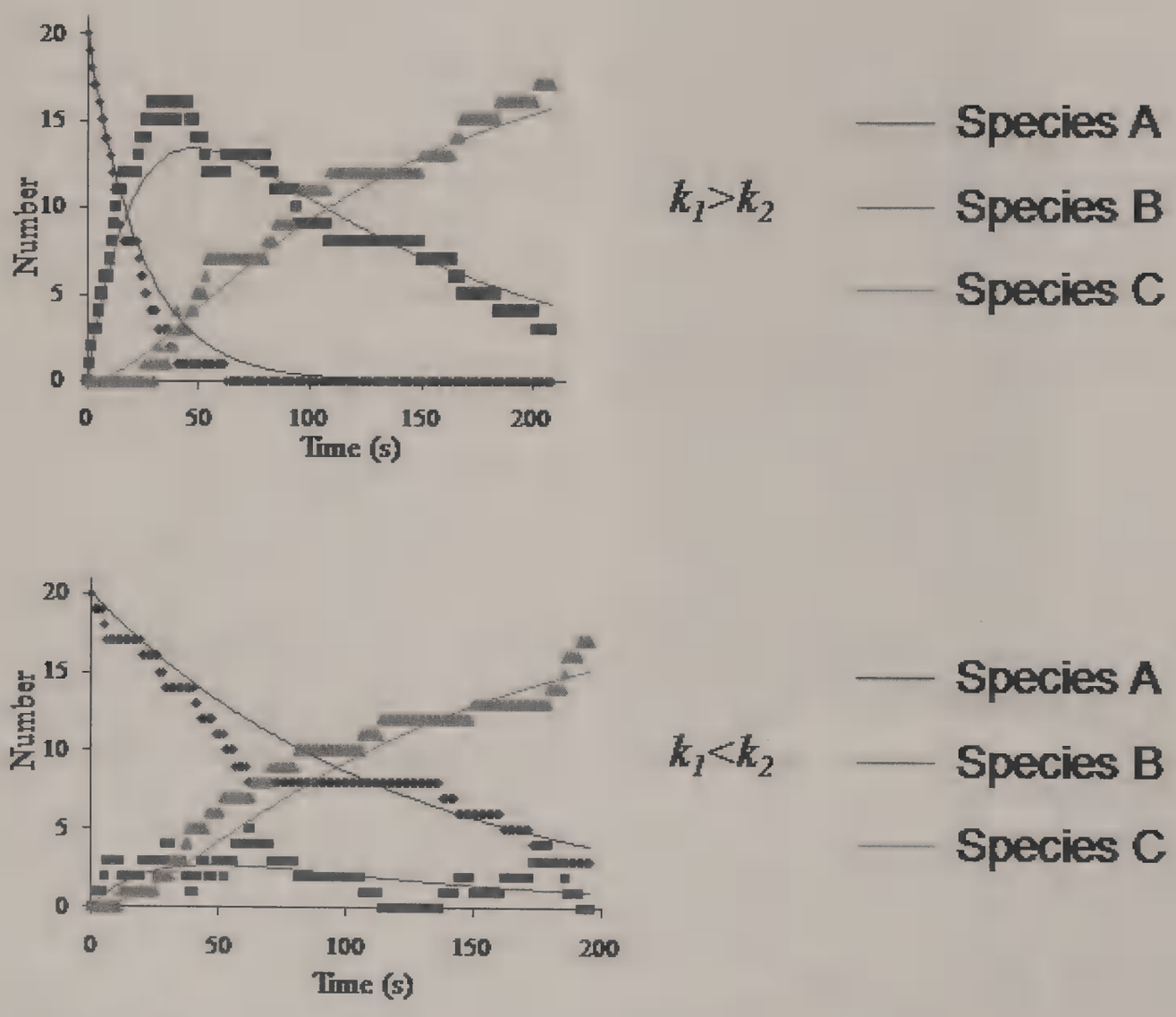

Figure 3. Dice rolling model-student-generated data with fit.

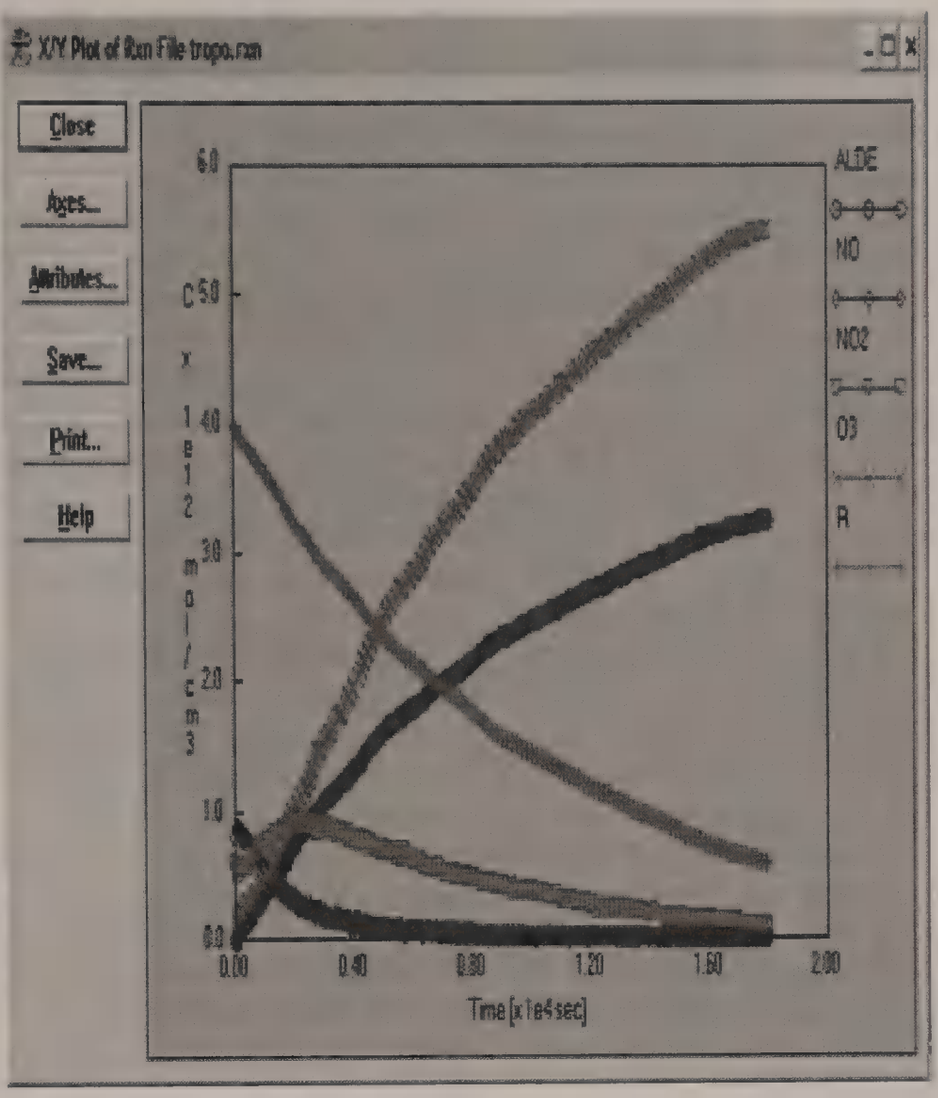

Figure 4. Example of data from kinetics simulation.

second column was made in which the small hole was between reaction chamber A and B and the larger hole was between B and C. Thus in the second tube, the rate-limiting step was the flow of water from A to B.

The modeling of the consecutive reaction was aken a step further when the participants were asked to model the reaction using a dice exercise. The probabilities of successful conversions of A to B, and of B to C, were defined and the participants used spreadsheets for analyzing and fitting the data (Figure 3). A thorough discussion of the impact of this sequence of kinetics exercises have been reported by Ruebush and North (2008).

On *Day 3*, the participants were asked to use a chemical kinetics simulator to try to model the concentration effects of NO_X and hydrocarbons on the tropospheric production of ozone. The goal of the inquiry was to generate an ozone isopleth, a visual approach to understanding the complex interplay between NO_X, VOC's and ozone in urban areas. The use of this visualization (Figure 4) enabled the participants to understand the non-linear relationship that exists in many chemical reactions.

During module one, authentic inquiry was characterized through the use of the black box exercise. The participants were encouraged to work in groups and collaborate to arrive at a model that supported the trends observed in the data. After the participants came to a consensus on a model within their group, they were asked to present and defend this model to the class. This exercise enabled the participants to analyze the data from many perspectives, and re-examine their own model after being exposed to an alternative model. Specific qualities of the nature of scientific models that emerged throughout the use of this exercise have been reported by Ruebush, Sulikowski, and North (in press).

During *days 2 and 3* of module one, the participants were asked to work with complex data sets (rolling the die, working with computer simulated data consisting of hundreds of points), and determine parameters for fitting and interpreting the data that was generated. Once each participant was satisfied with the fit to their

data, they were asked to combine their data, and present a single result as a class. This act of collaboration also showed the participants how acceptable rate constants for reactions are often refined through interaction of the scientific community. The sequence of exercises was designed to introduce the participants to various aspects of scientific modeling: (1) The development of models in the absence of pre-existing models—a minor activity in science; (2) the refinement of existing models and their parameterization; (3) the use of parameterized, refined models to ask new question and provide insight not possible without the assistance of model simulations.

Module 2-Simple and Complex Equilibria with Dr. Eric Simanek

Day 4 started with a discussion of a simple equilibrium (A↔B) and the definition of equilibrium constants in terms of both the familiar K_{eq} = [B]/[A] expression as well as the ratio of the forward and reverse rate constants. Dice rolling was adapted to model equilibrium as described in the introductory dialog: participants were given the opportunity to decide on their own rules and create their own spreadsheets for modeling the data. Upon mastery of simple equilibria, complex (A↔B→C) equilibrium was introduced and continued during *Day 5.* As evident in the introductory dialog, participants were thoroughly engaged during the design and implementation of their equilibrium models. An example of the type of data generated by the students for modeling complex equilibrium can be seen in Figure 5.

On *Day* 6, the contexts of these expressions were set using two examples: (1) herbicide fate in the environment and (2) metabolic pathways for degradation and the biodistribution of drug molecules. As an exiting exercise, participants built an *Excel* spreadsheet that depicted A↔B↔C →D and adjusted the rate constants so that [A] and [B] were high and approximately equal, [C] was low but detectable, and [D] increased with time. Time was also spent looking at the number of relevant examples found in recent newspapers to show the participants the correlations of this content with current events.

Authentic Inquiry was achieved throughout module 2 by showing the application of scientific concepts to real-life problems. The participants were able to see how complex data sets and models created in the laboratory can be implemented to solve and understand problems occurring in the environment around them. Participants underwent a step-wise progression to developing reaction modeling spreadsheets culminating in this module with the building of their own spreadsheet to model chemical equilibrium. This allowed them to engage in critical thinking and apply a variety

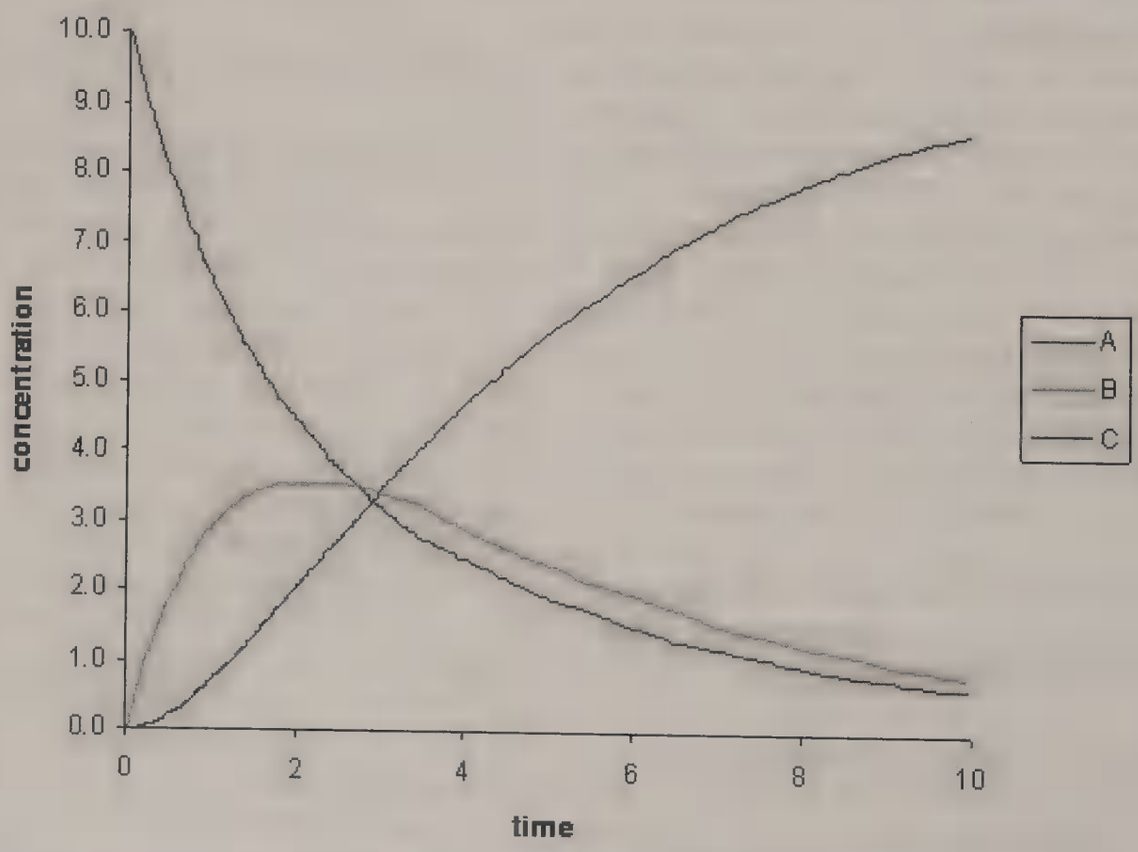

Figure 5. Example of changing concentrations over time for reaction scheme A↔B→C.

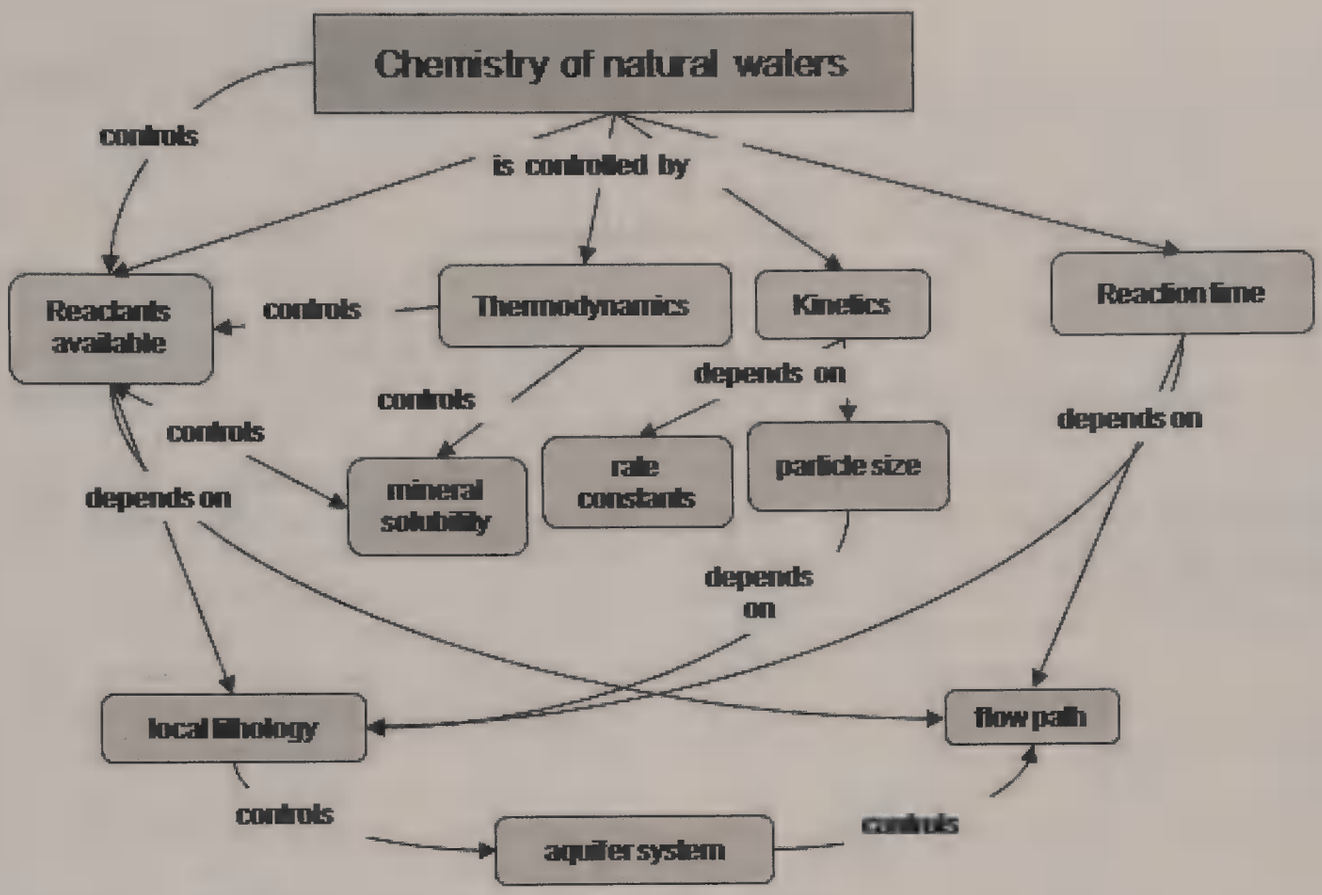

Figure 6. Concept map of the content covered during module 3.

of problem solving skills to closely related problems.

Module 3-Earth as a Chemistry Lab with Dr. Ethan Grossman

The world around us is a boundless laboratory for the study of chemistry. Module 3 focused on the natural chemical processes responsible for the quality and taste of the students' tap water (or "Why is Coors™ beer brewed in the Rocky Mountains?"). *Day 7* engaged the participants in analyzing drinking water that they had collected from the faucets in their homes. After an introductory lecture on the factors controlling natural water chemistry (Figure 6), the participants measured the specific conductivity of their waters and equated that to total dissolved solids (TDS) and water quality through calibration with a KCl standard. The students used *Excel* to record data, plot the standard calibration curve, and fit a trendline through that curve. In this way they could evaluate their tap water quality and compare it to bottled water and reverse-osmosis treated water. Using published drinking water chemistry data, the participants examined the different information gained when plotting the data as a pie diagram versus a line diagram. Natural water chemistry is controlled by chemical interactions between water and minerals. The first of two inquiry exercises on *Day 8* had the participants identify different minerals that affect ground water chemistry. The second inquiry activity incorporated the use of clear tubes filled with sand and reagents that would be found in different layers of sediment in a natural aquifer. These reagents (halite [NaCl], gypsum [$CaSO_4 \times 2H_2O$], and calcite [$CaCO_3$]) had different solubilities and different grain sizes. As pure water was poured through these "synthetic" aquifers, aliquots were collected from the bottom and analyzed for conductivity, pH, alkalinity, and sulfate. Data were compiled in an *Excel* spreadsheet and analyzed in a fashion similar to that done during the previous class period with drinking waters. This exercise demonstrated the role of mineral solubility and surface area on reaction rates and water quality.

Day 9 brought the participants back to the computers. They examined a computer model called PHREEQC. This computer model was written by Dr. David Parkhurst of the U.S. Geological Survey (Parkhurst & Appelo, 1999; http://wwwbrr.cr.usgs.gov/projects/GWC_coupled/phreeqc/) and modified for web use by Dr. Bernhardt Saini-Eidukat of North Dakota State University (NDSU) (http://www.ndsu.nodak.edu/webphreeq/). The model allows users to input water chemistry data and calculate activity coefficients and degree of saturation with respect to minerals. In this way students could determine whether their drinking water chemistry is controlled by equilibrium with a particular mineral, for example, calcite. The par-

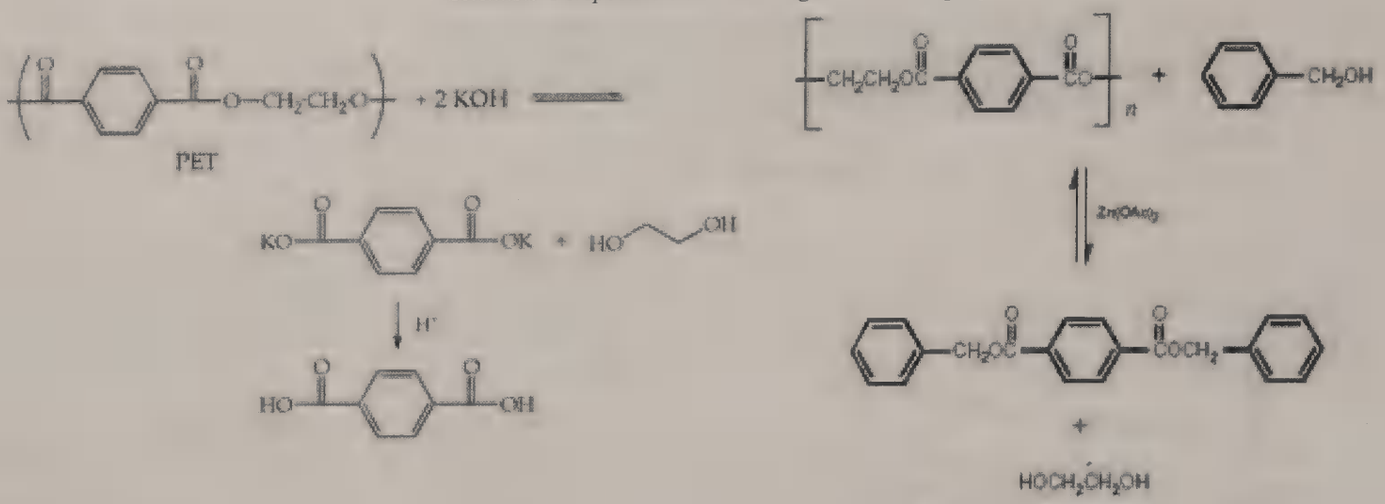

Figure 7. Reaction scheme for depolymerization of PET using KOH (left) and zirconyl chloride octahydrate (right) as catalysts.

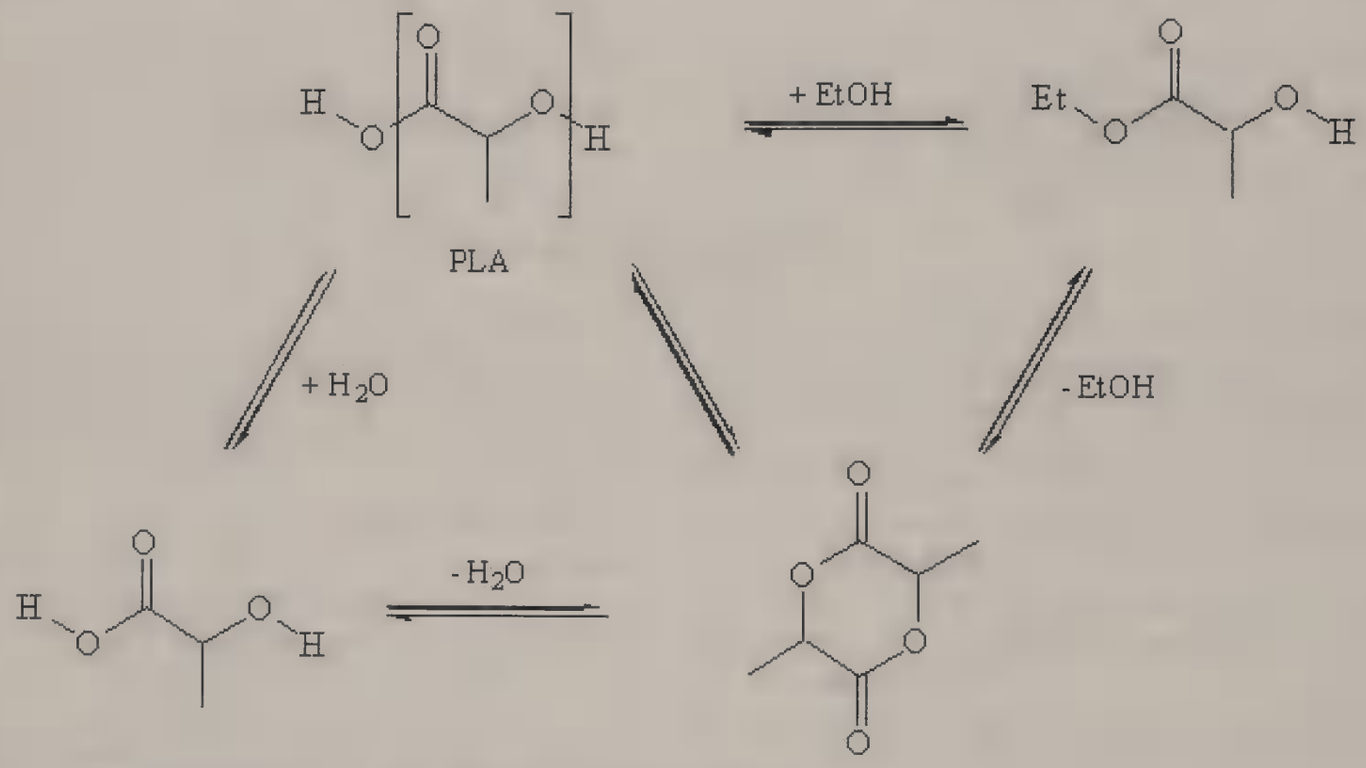

Figure 8. Reaction scheme for the depolymerization of PLA.

ticipants entered data from their drinking water samples and the synthetic aquifer demonstration to see how the minerals affected the chemistry. The participants seemed to take a vested interest in the ability to analyze and understand the chemistry in samples directly from their personal environment.

During module 3 the participants were able to see the effect of using multiple modeling tools and techniques to examine the same set of data from multiple perspectives. Many of them found this a useful tool for understanding how authentic inquiry can work in the classroom. This also gave the participants a viable model for readily implementing authentic inquiry into their classrooms. The theme of module 3, Earth as a Chemistry Lab, was a topic that many of them could see integrating into their classrooms. The topic excited them and could also excite their students. Thus, the participants were quick to ask questions during this module. Module 3 proved to provide a successful real world application of chemistry and authentic inquiry that the participants could easily bring back to their classrooms.

Module 4-Catalysis and Polymer Chemistry with Dr. Steve Miller

Module 4 began by asking the participants to explore the relationship between the uses of two different solvents, methanol and ethyl lactate, in a catalyzed reaction of a class of variously substituted organic compounds. The significance of comparing these two solvents is due to the fact that methanol is a widely used non- biorenewable solvent, whereas ethyl lactate

is a biorenewable solvent. The resulting products were subjected to analysis using a gas chromatogram. During the course of the analysis, the participants were also asked to prepare a set of standards for the calibration of the instrument.

On *Day 11* and *12*, participants examined the depolymerization of polyethylene terephthalate (PET) and polylactic acid (PLA), so-called biodegradable and/or recyclable plastics (Figure 7 and 8, respectively) using combinations of various catalysts and solvents suited to each reaction (Donahue, Exline, & Warner, 2003; Kaufman, Wright, Kroemer, & Engel, 1999; Nakayama, Sato, Ishihara, & Yamamoto, 2004). The participants were asked to inspect and compare the various reactions using visual inspection to determine the conditions under which a successful depolymerization took place. This allowed the participants to discuss what they were seeing and open the discussion for multiple interpretations from their team members. The participants seemed to enjoy these exercises; however, there was an overwhelming feeling of an inability to incorporate these exercises into their curriculum due to a range of factors including, cost of instrumentation, student interests and abilities, etc.

During module 4, authentic inquiry was characterized through the participant's ability to critique and characterize the ability of different chemical systems to perform at varying degrees of efficiency. These tasks required the students to participate in collaborative groups to analyze and interpret their data. As a class they had to determine what constituted successful versus an unsuccessful depolymerization. The participants were asked to work in collaborative groups to solve a problem in which there were various ranges of ability and prior knowledge within the group. As a result, the participants were able to engage in in-depth discussion about the laboratory activities.

Data analysis

An analysis of all notes and time spent on various tasks was performed using the journal maintained during observation. The analysis included reading the notes to find generalized themes between modules and a breakdown of time spent on various tasks individualized for each professor. Informal interviews conducted with participants and professors were analyzed to find general topics of success and areas for improvement. These items were qualitatively compared to one another to interpret the successes, improvements, and implications of the research.

Results and Discussion

Assessment and Feedback. On the last day of ITS, the participants presented their IF's to the group and science team leaders. The A&M faculty members were wholly impressed with these materials and no concerns about scientific accuracy were identified. Interestingly, a common theme throughout all of their IF's was the implementation of a pre-test to gauge student's prior knowledge and misconceptions of the topic of inquiry. The participants also expressed a favorable attitude towards learning about inquiry through actually being immersed in authentic inquiry activities themselves. Authentic inquiry was present throughout the three week session through the use of group problem solving, interpreting complex data sets, encouraging the participants to defend their scientific models and reexamine their findings in light of other people's interpretation of data. The participants reported that this made them feel more able to successfully implement inquiry in their classroom. The frustration felt by the participants made them understand what their students experience when they are asked to do an inquiry experiment.

Effectiveness of use of time spent with participants. According to Akerson and Hanuscin (2007), providing participants with mentors and models for implementing inquiry is a necessary component to maintaining a successful professional development program. The fact that all team leaders were able combine the use of IT, lecture and testing, data collection, and discussion enabled the team to model a variety of teaching and classroom management strategies. This provided participants with multiple viewpoints for analyzing a given technique for adaptation to their classroom instruction and management strategies (Loucks-Horsley & Matsumoto, 1999). An additional positive outcome of the interaction of the group was the transfer of the team leaders' enthusiasm for their field to the participants throughout the course of the various modules. A breakdown of the relative amount of time each science team leader spent engaging the participants in the use of IT, lecture and testing, data collection, and discussion can be seen in Figure 9.

The significance of the time spent in discussion was also invaluable to participants in terms of providing them with specific activities which could be brought back to the classroom. During discussion participants would often ask for clarification, alternative examples which would fit more readily into their classrooms, and

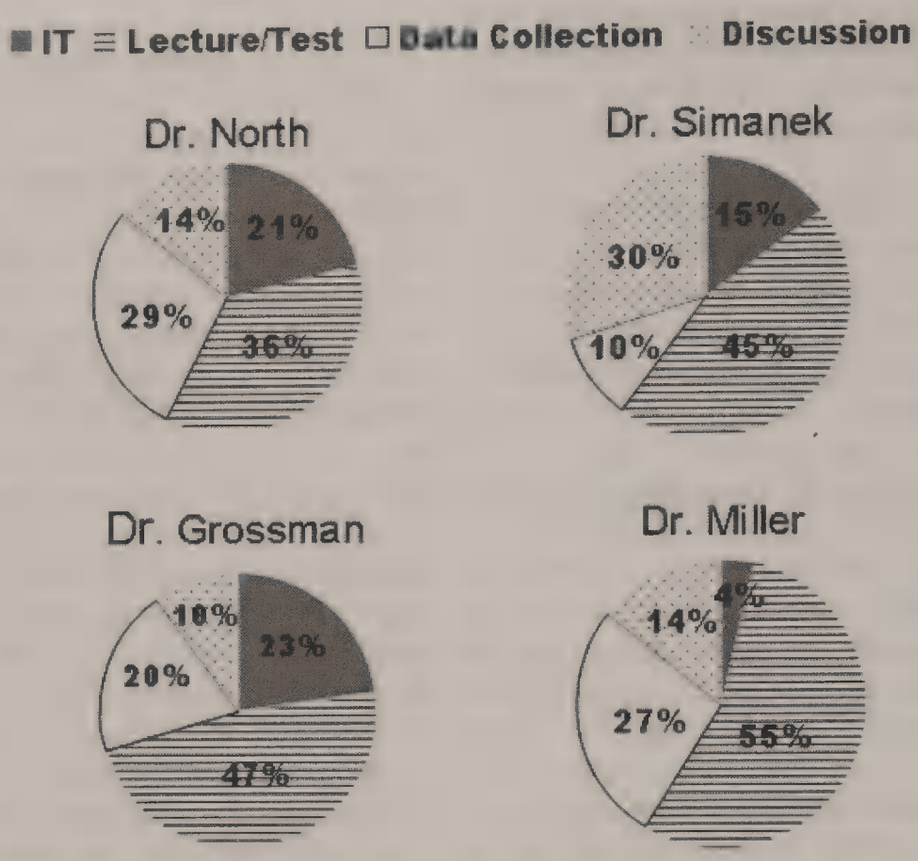

Figure 9. Summary of time spent by science team leader during morning sessions.

specifically address the state standards which they were required to teach. On the last day of the session, *the participants* presented their ideas in complete form to the remainder of the group and the science team leaders. This enabled the participants to receive immediate feedback and additional brainstorming for alternatives and extensions to their projects. These are opportunities which many researchers cite as a crucial step towards achieving long lasting changes in implementing new teaching strategies in the classroom (Akerson & Hanuscin, 2007; Garet, Porter, Desimone, Birman & Yoon, 2001; Loucks-Horsley & Matsumoto, 1999).

The opportunity for participants to engage in a variety of hands-on inquiry activities enabled them to develop teaching modules that integrate their new skills with required content. Research has shown that active engagement in inquiry activities increases the successful implementation of the inquiry activities in the classroom (Dresner & Worley, 2006; Garet et al., 2001; Loucks-Horsley & Matsumoto, 1999). The combination of the aforementioned qualities created an air of collegiality which has been noted by other researchers to greatly enhance the quality of the professional development experience for the participants (Akerson & Hanuscin, 2007; Dresner & Worley; Garet et al.; Loucks-Horsley & Matsumoto).

Perceptions of the participants. The participants identified several techniques that would aid them in their classroom including anthropomorphizing more difficult concepts, posing questions which had solutions with multiple interpretations, and new laboratory ideas and activities which they could implement in the classroom. For example, the complex expression A↔B→C was readily digested when A, B and C were locations such as the back of the classroom (typically the teacher's lab area), the front of the classroom, and the principal's office. Students concentrate at both areas in the classroom during the class period and move between them at different rates, but at some point, the teacher could banish them to the principal's office forever. The participants reported that having a team resource person, Mrs. Ruebush, available to help in the morning and who assisted in the afternoons to answer questions and clarify specific science content put them at an advantage.

The participants would have liked to see more material on the application of IT to instruction. Being that the participants enjoyed the inquiry exercises during summer I, the science team leaders have also expressed a desire to incorporate more "student-directed" inquiry into summer II.

Implications for Professional Development

Participants and MVE Team both believe that the best way to learn about teaching authentic inquiry is through immersion in an inquiry exercise. The black box exercise on the first day of the session quickly established inquiry immersion as a guiding principle that the faculty embraced and incorporated into subsequent days including dice experiments, modeling activities, and examination of physical models of aquifers. The participants saw these exercises as an effective way to teach many core laboratory skills, such as measurement, data recording, plotting and manipulation, as well as increasing the participants' abilities to defend the reasoning behind their hypotheses. Engaging the teacher participants in various forms of inquiry activities throughout the three week experience enabled them to approach creating an inquiry environment in their own classroom in a variety of manners. This experience supports professional development research encourages teachers to be directly engaged in inquiry experiences to enable them to successfully implement in their own classrooms (Akerson & Hanuscin, 2007).

Tool development and the subsequent application of these tools to open-ended questions was a successful and engaging activity. The participants found the progression of being given the tools to model the consecutive reactions or equilibria and then the progression to an open-ended approach to model the equilibrium reaction was very helpful. Ruebush and North (2008) reported the successful integration of this sequence of instruction and the use of dice as a pedagogical tool for understanding chemical reactions and first-order consecutive reactions.

Dice, as a simple tool for creating simulations, provide a useful mechanism for discussing chemical reactions, kinetics, and equilibrium. The participants reported that the analogy of reaction kinetics to dice rolling was a tool that could be easily integrated into their classrooms.

"Portability" from summer session to the classroom represents a critical bridge that participants and professors can build together. Many of the participants had the supplies and/or resources to obtain the materials needed to recreate the majority of the exercises in their classrooms. The participants mentioned the challenges of incorporating the sulfate test performed during analysis of the ground water. However, Dr. Grossman, the team leader for that module, was able to suggest that the participants perform a semi-quantitative analysis of the analyte through comparison with standards and visual inspection of turbidity. Dresner and Worley (2006) also reported the positive effects of science researcher partnerships in both increasing teachers' conceptual knowledge and informing their curricula developments upon completion of a similar professional development experience.

A lack of any common experience led to reticence. During module 4, catalysis and polymer chemistry, the participants' prior knowledge and experience using gas chromatography analysis varied. This created an interesting learning environment amongst them. Many of the participants who had prior experience with using a gas chromatogram seemed enthusiastic to get to analyze samples with the aid of the instrument. The participants who had little or no prior knowledge using the instrument were not as willing to participate in the preparation of the samples. During the sample preparation time, the participants who had prior knowledge helped explain the instrumentation to their other group members. This created an environment of collaboration but seemed to frustrate those with little experience. It seems that we may have overestimated the amount of prior knowledge and experience that the participants had with gas chromatography. We assume that the chemistry behind the method was probably not well retained with the participants due to the laboratory atmosphere; however, the exposure to an analytical instrument and interpretation of results aided in achieving the teams overall goals.

A modular approach to this three-week session is beneficial. Introducing the participants to a variety of instruction and research styles held by a group of scientists enabled them to gain a wide range of perspectives to integrate into their own teaching styles. The participants enjoyed being exposed to four different approaches to performing scientific research, teaching science, a variety of classroom management and lecture styles, and to the energy and excitement of the faculty members while presenting their respective topic (which did not wane over the brief 3-day modules). Because each A&M faculty member brought different research interests and experiences, the participants identified a range of contemporary topics and current events to bring into their classrooms. The exposure to this variety of research and instructional models has been shown to be an essential aspect of successful professional development experiences (Loucks-Horsley & Matsumoto, 1999).

Conclusions

The instructional approach taken by the science team leaders was successful. The participants enjoyed the variety of material and activities presented to them. The combination of the lecture in the morning and the implementation of many inquiry exercises was a key factor in the success of the course. The role of the CRP's was instrumental for the participants to create thorough and successful IFs. The presence of an additional team member who participated in both morning and afternoon sessions was also reported as being a significant contribution to the success of the group. The end-product presentations of the participants' IFs provided an excellent qualitative and holistic assessment of participant engagement an content mastery during the three week experience. An interesting component to assess the success of this type of professional development experience would be to formally increase the duration of contact with participant teachers when they go back to their classroom. Would the quality of their inquiry experiences increase with their students if they had direct communication with one of the participating scientist? What type of communication (e-mail, threaded discussion, blogs, etc.) would best benefit this population of learners?

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SHORT reports

Undergraduate Engineering Majors' Beliefs About Mathematics

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This study examined the mathematics beliefs of college students in 10 undergraduate mathematics classes at a large engineering school in the Midwest. The beliefs of 254 engineering majors were measured by the Indiana Mathematics Belief Scales and compared to the beliefs of elementary education majors and remedial college mathematics students obtained from earlier studies using the same instrument. The results were interpreted in terms of the students' daily attitudes towards their mathematics classes and corresponding academic and demographic parameters. The study showed that in many respects, the beliefs of the engineering majors were not that different from the other populations. The correlations among beliefs for the engineering group tended to be higher although there were relatively few significant correlations between belief and background variables. Attitude data were collected across a full semester for the engineering majors. The relatively modest day-to-day variation in those attitudes suggests that they are based on deeply seated beliefs.

Attitudes and beliefs about mathematics have become a widely acknowledged component of research on teaching and learning mathematics during the last two decades (Berkaliev, 2003; Kloosterman, 2002; Leder, Pehkonen, & Törner, 2002; Lesh & Zawojewski, 2007; McLeod, 1989a; Middleton & Toluk, 1999; Raymond, 1997). Along with the qualitative methods of research requiring extensive time resources, quantitative tools and techniques are also widely used in beliefs research due to their efficiency and generalizability. One of the instruments used frequently during the last 15 years is the *Indiana Mathematics Belief Scales* (*IMBS*) (Kloosterman, 1996, 2002; Kloosterman & Stage, 1992; Mason, 2003; Schommer-Aikins Duell & Hutter, 2005; Whitebread & Chiu, 2003). At the same time, despite its importance for the field, research on student beliefs about mathematics received relatively modest attention over the last 15 years between the publications of the first and second *Handbook of Research on Mathematics Teaching and Learning* (Grouws, 1992; Lester, 2007). One of the goals of this study was to revisit and apply the *IMBS* to a population of undergraduate engineering majors and compare those results to previously reported data on elementary education majors. Given that engineering majors tend to be better prepared in mathematics than elementary education majors, one would expect different patterns of beliefs. This study was also designed to identify and interpret patterns and correlations related to the measured beliefs about mathematics for the engineering majors themselves.

Participants

The participants for this study were 254 undergraduate students or 84% of the 303 students enrolled in 10 sections of required mathematics classes taken mainly by engineering majors. The selection of the 10 sections was based on enrollment, sufficient classroom size, meeting at least three and preferably four days a week, schedule (no more than three classes running concurrently), and on the instructor's consent. The selected 10 sections included 2 sections of introduction to calculus, 2 sections of calculus/pre-calculus-II, 2 sections of calculus-I, 3 sections of calculus-II (all of the above classes were at the 100 level), 1 section of introduction to differential equations (200 level), and 1 section of matrix algebra and complex variables (300 level). Of the 10 classes, 6 classes met four days a week and 4 classes met three days a week. Out of the 254 participants, 190 were male and 64 female, and 221 were of the U.S. nationality as compared to 33 of foreign nationalities. With respect to ethnicity, 144 participants

were White, 31 were Asian, 12 were Black, 17 were Hispanic, and the remainder were non-resident aliens or chose not to provide ethnic information. The vast majority of the participants majored in various types of engineering including aerospace, architecture, biomedical, chemical, civil, computer, electrical, and mechanical engineering. The participants' mean age was 19.7 years.

Method

On the first day of classes, the *Indiana Mathematics Belief Scales* were administered to all the 254 participants enrolled in the 10 mathematics classes. This instrument included five Likert-type scales consisting of six items each and measured the following beliefs about mathematics and mathematical problem-solving (Kloosterman & Stage, 1992):

Belief 1: *I can solve time-consuming mathematics problems.*

Belief 2: *There are word problems that cannot be solved with simple, step-by-step procedures.*

Belief 3: *Understanding concepts is important in mathematics.*

Belief 4: *Word problems are important in mathematics.*

Belief 5: *Effort can increase mathematical ability.*

In addition to these five scales, a six-item version of the Fennema-Sherman *Usefulness of Mathematics Scale* (Fennema & Sherman, 1976) developed by Kloosterman and Stage (1992) to go with the *IMBS* was integrated into the survey:

Belief 6: *Mathematics is useful in daily life.*

Individual item scores ranged from 1 (for the least positive response) to 5 (for the most positive response) with the score of 3 representing a neutral or uncertain response. Accordingly, total scores on each of the six scales could range from 6 to 30 with the score of 18 representing an overall neutral belief.

The first scale was developed to measure the belief, often found in college students as a result of their experiences in elementary and junior high school, that "all mathematics problems can be completed in five minutes or less" (Kloosterman & Stage, 1992; Schoenfeld, 1985, 1988). The second belief represented the nature of mathematical problem solving which, according to the *Principles and Standards for School Mathematics* (NCTM, 2000), "means engaging in a task for which the solution method is not known in advance" (p. 52). The third belief was related to the importance of conceptual understanding in mathematics as opposed to knowledge of procedures without understanding how and why these procedures work. This belief is of particular interest for engineering majors who are often asked to apply mathematics algorithms that have not been fully developed or proven. The fourth belief focused on the importance of being able to solve word problems as opposed to simply following algorithmic procedures. At the level of collegiate engineering education, this belief might be interpreted in terms of the importance of mathematical modeling (although this term was not explicitly used in the scale) as opposed to formal computational skills. Finally, the fifth and sixth beliefs were included because of their relation to student motivation to learning mathematics (Kloosterman, 1996). In addition, during the administration of the above-mentioned six belief scales, the participants also answered the question "How good are you at mathematics?" with five possible choices: excellent (5 points), above average (4 points), average (3 points), below average (2 points), and weak (1 point).

In addition to the belief scales, which were administered only once, participants were asked to complete the six-item *Attitudes toward Today's Mathematics Class* scale (Berkaliev, 2003) at the end of each class period for every session during the entire semester (a total of 73 days when the scale was administered). Daily administration of this attitude scale had the purpose of identifying and analyzing specific chaotic mathematical patterns in the dynamics of student attitudes. Analysis of these patterns is beyond the scope of this paper but, as outlined in the results section, the responses to these items also provided attitudinal information about the engineering student population. The six items represented the following six dimensions of student attitudes toward their current math sessions: (1) enjoyment, (2) confidence, (3) boringness, (4) importance for life, (5) frustration, and (6) importance for future career. These items were:

1. I enjoyed today's math class.
2. I know I did well in today's math class.
3. Math problems solved today were boring for me.
4. The math topic we covered today was very important for everyday life.
5. I was confused in today's math class.
6. It was easy to see how the material I learned today will help in my career.

The original version of this scale consisted of 36 Likert-type items and contained six sub-scales (6 items in each sub-scale). This scale, however, was too long to repeat on a daily basis. The initial scale was adminis-

Table 1
Means, Standard Deviations, and Reliabilities (Cronbach's α) for Engineering as Compared to Other Majors

	Engineering Majors (n = 251)			Remedial Math (n = 273) & Elementary Math Methods (n = 244)		
Scale	Mean	S.D.	Cronbach's α	Mean	S.D.	Cronbach's α
Difficult Problems	22.4	4.0	.80	20.5	3.7	.77
Steps	16.4	3.0	.50	16.5	3.4	.67
Understanding	23.9	3.6	.81	25.3	2.8	.76
Word Problems	18.7	3.2	.52	18.8	3.0	.54
Effort	23.4	3.9	.89	22.4	3.8	.84
Usefulness	24.5	4.3	.87	23.2	4.2	.86

Note:
Difficult Problems = I can solve time-consuming mathematics problems
Steps = There are word problems that cannot be solved with simple, step-by-step procedures
Understanding = Understanding concepts is important in mathematics
Word Problems = Word problems are important in mathematics
Effort = Effort can increase mathematical ability
Usefulness = Mathematics is useful in daily life

tered to 63 students enrolled in three sections of a problem-solving mathematics course for preservice elementary teachers (Cronbach's α = .92), and the item with the highest item-total correlation was selected from each of the six sub-scales. Item 6 was slightly reworded in order to reflect the shift in student populations from preservice elementary teachers in the pilot study to various engineering majors in the current study.

Results

Table 1 shows means, standard deviations, and internal reliabilities (Cronbach's α) of the current administration of the *Indiana Mathematics Belief Scales* in comparison to the original study by Kloosterman and Stage (1992). In the original study, the scales were administered to a population of 273 college students enrolled in a remedial mathematics course and 244 students enrolled in an elementary mathematics methods course. As shown in Table 1, the reliabilities in the current study were almost identical except for the *Steps* scale where the Cronbach's α was significantly lower in this study (.50) than in previous research using the Indiana scales. With α this low on the *Steps* scale, it is difficult to draw inferences from the data collected using the scale.

The mean scores on the *Steps* and *Word Problems* scales (Table 1) were quite similar for the engineering majors (this study) and elementary education majors and remedial math students (Kloosterman & Stage, 1992). Mean scores on the *Difficult Problems, Usefulness*, and *Effort* scale were a bit higher for the engineering majors, while the mean score on the *Understanding* scale was a bit lower. The standard deviations for all the scales were at about the same level except the *Understanding* scale for which the standard deviation was a bit higher for the engineering majors.

Table 2 shows correlations among each of the six belief scales used in the current study as compared to the correlations found by Kloosterman and Stage (1992). As can be seen in the table, the pattern of correlations is the same for the two studies although a greater number of statistically significant correlations, higher statistical significance, and overall larger correlations appeared in the current study. In particular, 7 out of the 15 new correlations are greater or close to 0.3. The only exception is the *Steps* scale which had a bit lower correlation with the *Effort* scale in the current study as compared to the Kloosterman and Stage study. As mentioned earlier, this scale had a relatively low reliability in the current study which is likely related to the low correlations.

To simplify the data from the six attitudinal items that were administered daily, mean scores on each item were calculated for each student across the semester.

Table 2
Inter-Scale Correlations for the Current (regular font, n=252) and Kloosterman & Stage (1992) Studies (italics, n=517)

Scale	1	2	3	4	5	6
1. Difficult Problems		-.13*	.50**	.20**	.40**	.56**
2. Steps	*-.04*		-.06	.10	-.16**	-.07
3. Understanding	*.23**	*-.02*		.29**	.28**	.44**
4. Word Problems	*.14**	*.06*	*.18**		.07	.13**
5. Effort	*.29**	*-.27**	*.19**	*-.05*		.39**
6. Usefulness	*.48**	*.06*	*.33**	*n.a.*	*.30*	—

* $p < .05$
** $p < .01$

Table 3
Correlations of Attitudes (n = 223)

	2	3	4	5	6
1. Enjoyment	.48**	.59**	.52**	.38**	.42**
2. Confidence		.03	.20**	.70**	.18**
3. Boringness			.46**	.13	.35**
4. Importance for Life				.11	.81**
5. Frustration					.08
6. Importance for Career					—

** $p < .01$

Table 3 shows correlations among the means of the six items. As can be seen, there were a number of statistically significant correlations, most of which were strong or moderately strong. However, there were identified no statistically significant correlations between the means and any of the *Indiana Mathematics Belief Scales*. Of interest, is that there were a number of statistically significant correlations (most of which were negative) between scores on the *IMBS scales* and the standard deviations of the daily attitudes toward math class scores. However, all of those correlations were less than 0.3. The two largest correlations were provided by the *Word Problems* belief with the standard deviations of *Importance for Life* ($r = -.24, p < .05$) and *Importance for Career* ($r = -.20, p < .05$).

Table 4 shows correlations between scores on the *IMBS* and some of the academic parameters. As can be seen, all of those correlations were considerably less than 0.3 except the correlations of self-evaluation of ability with the *Difficult Problems* ($r = .51$) and the *Usefulness* ($r = .29$) scales. At the same time, there were almost no statistically significant correlations between any of the academic parameters and average daily attitudes toward math class – the strongest one occurred between self-evaluation and the importance of math class for life, ($r = -.19, p < .05$). Finally, the mean scores and standard deviations of the beliefs and daily attitudes provided generally similar patterns for the male and female subpopulations of students. And although most of the overall mean scores and standard deviations were slightly greater for the female group of students, a *t*-test revealed no significant gender differences, and therefore all the results are reported for the entire group of participants as a whole.

Discussion

As noted, the reliabilities of the six belief scales provided by the current and Kloosterman and Stage (1992) studies were very similar except for the *Steps* scale where the reliability was significantly lower in the current study than in the Kloosterman and Stage study. One possible explanation for the low reliability in the

Table 4
Correlations of Beliefs and Self-Evaluation (n = 210), SAT/ACT (n = 196), GPA (n = 228), Course Grade (n = 228), Age (n = 228), and Number of Math Classes Taken (n = 228)

Scale	Self-Evaluation of Ability	SAT	GPA	Course Grade	Age	Number of Math Classes
Difficult Problems	.51**	.16*	.23**	.21**	-.05	.02
Steps	.09	-.00	.07	.14*	-.03	.11
Understanding	.21**	.02	-.01	.02	-.04	-.05
Word Problems	.05	.08	.15*	.03	.03	-.09
Effort	.18**	-.15*	.09	.07	.11	-.03
Usefulness	.29**	-.01	.05	.11	-.03	-.05

* $p < .05$
** $p < .01$

current study is that use of the term "word problem" is not consistent across mathematics teachers and textbooks. Moreover, this term may be interpreted differently in the context of college level calculus sequence classes for engineering majors as opposed to K-12 curriculum and methods classes for education majors. This inconsistency could be exacerbated by the fact that about 13% of the participants of the current study were from countries outside of the United States where the term "word problem" also may have different interpretations. Finally, in terms of "step-by-step" procedures scale per se, the scale's lower reliability might be related to the nature and traditions of engineering education where algorithmic and procedural applications of mathematics are more common than in traditional mathematics programs.

An open question in the literature on student beliefs has been the extent to which students in quantitative disciplines have different beliefs than those in disciplines that depend less on mathematics (Kloosterman, 1996). The means reported in Table 1 suggest that even though engineering majors have stronger mathematics backgrounds than any of the remedial mathematics students surveyed by Kloosterman and Stage (1992) and stronger backgrounds than many of the elementary education majors, their beliefs as measured by the *Indiana Mathematics Belief Scales* are fairly similar. One possible explanation for the fact that the mean scores on the *Difficult Problems, Effort*, and *Usefulness* scales displayed by the engineering majors enrolled in calculus sequence classes were slightly greater is related to the issues around reliability of the *Steps* scale. Specifically, the fact that calculus sequence classes for engineering majors have more math prerequisites compared to remedial and elementary mathematics methods classes means that students in these classes have gone farther in mathematics and thus have more confidence (measured by the *Difficult Problems* scale), see effort (*Effort* scale) as making a difference because their efforts have paid off, and see the application of mathematics (*Usefulness* scale) in engineering. Another factor could be the initial predisposition of engineering students to solving time-consuming technical problems. At the same time, the fact that the engineering majors as a group had lower mean scores and higher standard deviations on the *Understanding* scale is likely related to the more procedural nature and traditions of engineering education.

As shown in Table 2, the majority of correlations in the current study were more significant and relatively stronger than the corresponding correlations in the Kloosterman and Stage (1992) study. The strongest correlations identified in the current study were found in the *Difficult Problems, Understanding, Effort*, and *Usefulness* scales all of which measured beliefs about the individual as a learner of mathematics. In contrast, the weakest correlations were provided by the *Steps* and *Word Problems* scales which measured beliefs about the discipline of mathematics itself. As noted earlier in this paper, the weaker correlations may be in part explained by the inconsistency of the "word problem" term usage and by the difference between the natures of mathematics courses for preservice engineers versus preservice elementary teachers. It is interesting to note here that the negative correlation between the *Steps* and *Effort* scales provided by the current study ($r = -.16$) is

considerably closer to zero than in the Kloosterman and Stage (1992) study (r = -.27). This might mean that the hypothesis "those students who think that word problems can be reduced to step-by-step procedures are the same students who feel that effort will improve their ability" would be less true with respect to the engineering majors than with respect to the elementary education majors. This, in turn, might mean that it was less likely that step-by-step solution of word problems was the key to success in the calculus sequence courses for the engineering majors than in the remedial and mathematics methods courses taken by the elementary education majors. Table 2 also suggests that the three beliefs about learning mathematics (i.e., ability to solve time-consuming math problems, conceptual understanding of mathematics, and effort as the key for success) were associated with each other to a significantly greater extent among the engineering majors than among the elementary education majors. This pattern might be explained by the fact that the calculus sequence math classes taken by the engineering majors required stronger mathematics background and mathematical predisposition rather than the courses taken by remedial and methods students.

As can be seen from Table 3, overall mean scores of attitudes toward math class provided some strong and significant correlations generally consistent with existing attitudinal research (Ma, 1997; Ma & Kishor, 1997; Rech, Hartzell, & Stephens, 1993; Taylor, 1997). Not surprisingly, the strongest correlation occurred between the feeling of *Importance for Life* and the feeling of *Importance for Career* with respect to mathematics class. The next strongest correlation in this table occurred between confidence about math class and the lack of frustration. The strength of this correlation, which was the only strong correlation with confidence, is not surprising. The only nonsignificant correlations occurred between frustration and boringness, importance for life, and importance for career; and between boringness and confidence. There has been little research on boringness to compare with this result, but intuitively there is little reason to think there should be strong relations between boringness and these variables.

At the same time, there were no statistically significant correlations between the measured beliefs about mathematics, on the one hand, and mean daily attitudes toward math class, on the other. This aligns with the notion that, in contrast to day-to-day attitudes toward math class which are sensitive to classroom factors and can change frequently, beliefs about mathematics are more deeply seated and stable and, accordingly, more resistant to change (McLeod, 1989b).

However, interestingly enough, there were a relatively greater number of statistically significant and slightly stronger correlations (most of which were negative) between the beliefs about mathematics and the standard deviations of the dynamics of daily attitudes toward math class. This might suggest a hypothesis that more positive beliefs about mathematics can be associated to some extent with more stable daily attitudes toward math.

In particular, the above-mentioned significant negative correlations between the *Word Problems* scale, on the one hand, and the standard deviations of the *Importance for Life* and *Importance for Career* attitudes, on the other, mean that those students who valued the importance of word problems in mathematics were more likely to display more consistent and stable daily attitudes toward the importance of their mathematics class. One of the specific practical curricular implications here might be more focus on meaningful and interesting word problems for engineering majors and other students taking calculus sequence classes.

As shown in Table 4, 10 of 36 correlations between the beliefs about mathematics and academic parameters were statistically significant. The two parameters with the largest number of significant correlations with other parameters were the *Difficult Problems* scale and students' math self-evaluation. Moreover, the correlation between these two parameters (r = .51) was the highest of those assessed. At the same time, the correlation between self-evaluation and effort was also statistically significant but much smaller (r = .18). Interestingly, this means that those students who gave themselves higher scores on how good are they at mathematics also tended to believe that they can solve time-consuming math problems, but, at the same time, were not unusually prone to believe that effort can increase mathematics ability. The fact that this belief was displayed by the engineering majors who were self-confident and presumably able to solve time-consuming math problems suggests that those who are good at mathematics may think their skills are as much a result of their "innate" ability as their effort.

In contrast to the large number of significant correlations among the belief variables, there were almost no significant correlations between daily attitudes toward mathematics class and academic parameters. This might once more somewhat support the hypothesis

about the unstable and changing character of immediate attitudes toward math class and dependence on a number of extraneous factors from the outside of the classroom. As mentioned earlier, the only correlation of interest occurred between mathematics self-evaluation and importance of class for life. This negative correlation means that some of the students who gave themselves higher scores on how good they are at math were also likely to express slightly more negative attitudes about the importance of the day's mathematics class. This pattern suggests that more self-confident engineering majors tended to see the content of their mathematics classes as more abstract and formal. One of the possible curricular implications here is that a greater number of meaningful examples connecting the content of calculus sequence classes for engineering majors with their daily lives would be appropriate.

Conclusions and Recommendations

This study revealed a substantial number of similarities but also some differences in beliefs about mathematics of engineering students as compared to students enrolled in college remedial mathematics classes or elementary mathematics methods courses. The means on the belief scales for the two populations were similar and the general pattern of correlations among beliefs was also similar. On the other hand, engineering majors tended to have slightly stronger beliefs with respect to themselves as learners, and the number and strength of correlations among beliefs was also a bit stronger for the engineering majors. The data suggest that the term "word problem" was interpreted in the context of calculus sequence classes for engineering majors even more inconsistently than in the context of remedial mathematics and mathematics methods classes for elementary education majors. Given the importance of word problems and problem solving (NCTM, 2000), this might be evidence of a need for greater attention to this issue not only in K-12 mathematics education, but also in the mathematics education of engineers. The more articulated, consistent, correlated, and significant beliefs about themselves as learners of mathematics (as opposed to beliefs about the discipline of mathematics) of the engineering majors is likely related to the formal math prerequisites and initial math predisposition of these students. On the contrary, engineering majors had less consistent beliefs about the discipline of mathematics itself not only with respect to the specific term "word problems" but also with respect to the importance of conceptual understanding versus algorithmic procedures in mathematics which can be in part explained by the historical traditions in engineering education and its focus on procedural applications of algorithms rather than their theoretical understanding. This, in turn, raises an old question about what kind of mathematics should be taught to engineering majors and what should be the relationship between procedural versus conceptual math knowledge with respect to this category of students.

Finally, this study indirectly supports the hypothesis that beliefs about mathematics are more stable and deeply felt than day-to-day attitudes toward a mathematics class, which tend to be easily affected by a number of external factors. There is very little research on how attitudes vary from day to day in classes, and the significant negative correlations between background and belief variables in comparison to the variance (standard deviation) of the daily attitude measures suggest that indeed more positive beliefs and stronger math background and performance – rather than strength of attitudes – lead to more stable and predictable day-to-day patterns of attitudes towards mathematics. This last hypothesis might be useful, in particular, for the diagnosis of patterns of anxiety in mathematics classroom and subsequent student counseling and advising.

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Inquiry in the Classroom: Realities and Opportunities

Editors: Eleanor Abrams, Sherry Southerland and Peggy Silva

Information Age Publishing
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Charlotte, NC 28271

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Reviewer: Paul Narguizian
California State University, Los Angeles
Los Angeles, CA 90032

In an era of national and state academic standards, high-stakes testing, and, teacher accountability, the topic of inquiry-based learning and assessment has taken on a greater meaning in both pre-service and in-service teacher education programs and science classrooms across the nation. Of special importance is its grounding in issues and practices relating to the various forms of inquiry teaching along with the different factors which influence its integration in the classroom. In *Inquiry in the Classroom: Realities and Opportunities*, edited by Eleanor Abrams, Sherry Southerland and Peggy Silva, the reader is led on a path of discovery and *inquiry* (pun intended) into the world of inquiry-based learning and teaching by a wide array of experts in the field. The book is meant for persons involved in science education, educational policy and reform institutes, the National Science Foundation, school administration, classroom teaching, science teacher education at the university level, and the development of standardized and authentic assessment.

The central focus of the book deals with inquiry teaching, its various forms and what factors influence its integration into the science classroom. The introduction includes a relatively extensive literature review of various definitions and practices of inquiry found in the research literature. The editors along with the various authors point to the critical need for defining *what inquiry is and what it looks like within the science classroom*. Having this central theme in mind, the editors organized the text into six sections, which cover numerous challenges while at the same time providing solutions in inquiry-based learning and teaching strategies. Each section begins with one or more vignettes taken from various science classrooms describing a critical feature(s) of inquiry. The first section, entitled: *Students' Knowledge and Skill With* deals with learning about inquiry from a students' perspective along with the development of skills teacher needs to effectively plan inquiry experiences within the classroom. The proceeding five sections include headings such as: *Selecting and Using Inquiry Approaches to Teach Science: The Influence of Context in Elementary, Middle, and Secondary Schools, Accommodating Student Diversity Within Inquiry, Standardized Tests and Inquiry: How the Accountability Movement Acts to Prevent Changes in Science Classrooms, Teacher Knowledge and Enhancing Inquiry,* and *Student-Scientists Partnerships: Exploring One Example of Inquiry in the Classroom.* I found this type of organization to be highly advantageous. Based on the background information for each of the proceeding sections readily provided in the beginning of the text, the reader relates to the main point(s) of the various authors with greater clarity and insight.

While the book tries to consider how to increase and improve inquiry teaching and learning, the practical information available to science teachers to better inform their inquiry-based instructional strategies and varied assessment practices is cursory at best. Despite this limitation, *Inquiry in the Classroom: Realities and Opportunities* is a valuable resource to the literature of pre-service and in-service science teacher education.

3 – D Computer Graphics: A Mathematical Introduction with OpenGL

Author: Samuel R. Buss

Cambridge University Press
40 West 20th Street, New York, NY 10011-4211

2003; 392 pages
ISBN: 0 521 82103 7

Reviewer: Medhat H. Rahim
Lakehead University
Thunder Bay, Ontario, Canada P7B 5E1

This text has been shaped by the author's experience as a mathematician and in particular his participation in a range of applied computer projects, including projects in computer games and virtual reality. Initially the text was immerged on the basis of the author's earlier teaching a mathematics class on computer graphics and geometry. By then, it has been decided to meet the need for a text that would bring together the mathematics theory underlying computer graphics in an introductory and unified fashion. The text highlights the phenomenal growth of computer graphics in recent decades, progressing from simple 2-D graphics to high quality, complex and dynamic, 3-D graphics that are doable through the use of nowadays much improved personal computers and home game consoles to the extent that low-cost systems are able to display millions of images per second. In particular, the main purpose of this text may be succinctly described as to present the mathematical foundation of computer graphics along with a practical introduction to programming using OpenGL environment.

Further, for convincing 3-D computer graphics, this text explains thoroughly the requirement of software capable of displaying 3-D images in that the required software must keep track of the motion of multiple objects; and maintains information about the colors, lighting, and textures of many objects and displaying these objects on the screen at 30 or 60 frames per second. It should not be a surprise that 3-D computer graphics does require an extensive amount of mathematics such as geometry, calculus, linear algebra, numerical analysis, abstract algebra, data structures, and algorithms. This would portrait mathematics as an interdisciplinary elegant subject in the eyes of many.

There are 12 chapters with two appendices in the text. Chapter 1 deals with double buffering for animation with some background on coordinates, points, lines, and polygons and display models. Chapter 2 covers transformations and viewing in 2- and 3-D spaces with mapping to pixels. Chapter 3 deals with lighting, illumination, and shading while Chapter 4 covers averaging and interpolation. Chapter 5 covers texture mapping and Chapter 6 deals with color perception, and representation of color values. Chapter 7 provides details on Bezier smooth curves while Chapter 8 deals with B-Splines curves. Chapter 9 discusses the ray tracing techniques both basic and advanced ray tracing. Chapter 10 deals with intersection tracing covering fast intersections with rays in addition to pruning intersection tests while Chapter 11 covers the radiosity equations and their solutions. Finally, Chapter 12 discusses animation of position with representation of orientations and the concept of kinematics which refers to the purely geometric properties of motion such as position, orientation, velocity, and rotational velocity. In addition, two appendices, A and B, are added where Appendix A offers a quick review of the mathematical prerequisites for the text and B offers a ray tracing package, prepared by the author, that implements recursive ray tracing and that the package and its source code are freely available and can be downloaded from the text's Web site.

This computer science text is designed for use with advanced junior- or senior-level university courses or introductory graduate courses. Further, individuals studying this text have to be acquainted with OpenGL programming environment which in tern requires the reader to be familiar with C, C++ and perhaps with Java computing languages. As such, this text is suitable for computer science graduate students with a limited access for those mathematics/science teachers who lack the prerequisites mentioned above.

This text is an essential and useful reference for studying and understanding the basis for the mathematical foundation of computer graphics in 2- and 3-D along with a practical introduction to programming using the OpenGL environment. Its place in any library is a must.

PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to: Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel; or fax to:972-86-477-648. Questions concerning proposals and/or solutions can be emailed to: eisenbt@013.net. Solutions to previously stated problems can be seen at: ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before May 15, 2009

5056: *Proposed by Kenneth Korbon, New York, NY.*

A convex pentagon with integer length sides is inscribed in a circle with diameter $d = 1105$. Find the area of the pentagon if its longest side is 561.

5057: *Proposed by David C. Wilson, Winston-Salem, N.C.*

We know that $1+x+x^2+x^3+\cdots=\sum_{k=0}^{\infty}x^k=\frac{1}{1-x}$ where $-1<x<1$.

Find formulas for $\sum_{k=1}^{\infty}kx^k, \sum_{k=0}^{\infty}k^2x^k, \sum_{k=0}^{\infty}k^3x^k, \sum_{k=0}^{\infty}k^4x^k$, and $\sum_{k=0}^{\infty}k^5x^k$.

5058: *Proposed by Juan-Bosco Márquez, Valladolid, Spain.*

If p, r, a, A are the semi-perimeter, inradius, side, and angle respectively of an acute triangle, show that

$$r+a\le p\le\frac{p}{\sin A}\le\frac{p}{\tan\frac{A}{2}},$$

with equality holding if, and only if, $A=90°$.

5059: *Proposed by Panagoite Lignouras, Alberobello, Italy.*

Prove that for all triangles ABC

$$\sin(2A)+\sin(2B)+\sin(2C)+\sin(A)+\sin(B)+\sin(C)+\sin\left(\frac{A}{2}\right)+\sin\left(\frac{B}{2}\right)+\sin\left(\frac{C}{2}\right)\le$$

$$\frac{6\sqrt{3}+1}{8}.$$

5060: *Proposed by José Luis Díaz-Barrero, Barcelona, Spain.*

Show that there exists $c \in (0, \pi/2)$ such that

$$\int_0^c \sqrt{\sin x}\,dx + c\sqrt{\cos c} = \int_c^{\pi/2} \sqrt{\cos x}\,dx + (\pi/2 - c)\sqrt{\sin c}.$$

5061: *Proposed by Michael P. Abramson, NSA, Ft. Meade, MD.*

Let $\{a_j\}$ be a sequence of positive integers. Prove that

$$\sum_{i_m=1}^{n} \sum_{i_{m-1}=1}^{i_m} \cdots \sum_{i_1=1}^{i_2} a_{i_1} = \sum_{i=1}^{n} \binom{n-i+m-1}{m-1} a_i.$$

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   On reference list: Author (2005). Journal Title. (Do not include title of article or volume and page #)
3. Graphics submitted as publication-ready copy on white background with black type. Each table or figure should be on separate page at the end of the manuscript, with a note within the ms where the graphic should be placed. Use no smaller than 8-point font for text on figures; use no smaller than 11-point font for tables. Figures and tables should be no wider than 4.75 inches.

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Addresses K through graduate classroom or teacher education issues
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Theoretical/literature-based framework

Research manuscripts only:

Design and methodology
Analyses of data
Conclusions based on results
Results related to professional practice and literature
Enough information to enable replication (quantitative)

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IN THIS issue

Research Articles

Interesting Science and Mathematics Graduate Students in Secondary Teaching

Carmen M. Latterell

State and national initiatives attempt to increase the quantity and quality of secondary mathematics and science teachers. Research suggests that if one could appeal to something inside of people or about the process of teaching and learning itself, then one might draw current mathematics and science graduate students into secondary teaching. This study placed eight mathematics and science graduate students in secondary schools for ten hours a week. Pre- and post-measures of their interest level in becoming secondary teachers were made. Overall, graduate students decreased in their desire to become secondary teachers.

A Cross Discipline Study of Reformed Teaching by University Science and Mathematics Faculty

Lawrence B. Flick, Pejmon Sadri, Patricia D. Morrell, Camille Wainwright, Adele Schepige

Researchers observed 28 university faculty in graduate and undergraduate science and mathematics courses in a three-year, longitudinal study of teaching. Subjects were selected from five higher education institutions in the state where faculty had a two- to five-year association with a reform-based NSF professional development program. Observer field notes and a researcher-designed observation instrument were used to describe and compare teaching practices. The participants in this study taught science and mathematics content courses for majors, non-majors, as well as education majors. Our observation method created a descriptive profile that enabled comparisons across a variety of teaching contexts. The main results showed that the faculty lacked practices that supported development of divergent thinking, conceptual thinking, and metacognitive thinking skills.

Turkish Prospective Chemistry Teachers' Alternative Conceptions about Acids and Bases

Yezdan Boz

The purpose of this study was to obtain prospective chemistry teachers' conceptions about acids and bases concepts. 38 prospective chemistry teachers were the participants. Data were collected by means of an open-ended questionnaire and semi-structured interviews. Analysis of data indicated that most prospective teachers did not have difficulties about macroscopic properties of acids and bases. However, despite chemistry instruction, most of the prospective teachers were found to have problems in understanding the neutralization concept, the distinction between strength and concentration of acids and linking the acids and bases topic to daily life. These findings have some implications for teacher education programs.

Crossing the Barriers Between Preservice and Inservice Mathematics Teacher Education: An Evaluation of the Grant School Professional Development Program

Damon Bahr, Eula Ewing Monroe, Mark Balzotti, Dennis Eggett

A 2-year school-based mathematics professional development program is described and evaluated after its first year of implementation. Included in this program as its first course was a unique methods course in elementary education involving both preservice students and inservice teachers who cooperatively studied and applied reform pedagogy. The program resulted from the collaborative efforts of two institutions of higher education, a neighboring school district, the principal and teachers of one school within that district, and the state office of education. Evaluation of the first year of the program consisted of assessing the beliefs and perceptions of both preservice students and inservice teachers, along with an assessment of the mathematical achievement of the children within the classes of those teachers. Pre- and post-assessments of the preservice students and inservice teachers' beliefs regarding reform pedagogy were administered using the IMAP [Integrating Mathematics and Pedagogy] Web-Based Beliefs Survey (2006). Likert scale surveys were used to assess perceptions regarding course climate and participant relationships from both teacher groups. An additional evaluation will be conducted following the second year of the program.

Interesting Science and Mathematics Graduate Students in Secondary Teaching

Carmen M. Latterell
University of Minnesota Duluth

State and national initiatives attempt to increase the quantity and quality of secondary mathematics and science teachers. Research suggests that if one could appeal to something inside of people or about the process of teaching and learning itself, then one might draw current mathematics and science graduate students into secondary teaching. This study placed eight mathematics and science graduate students in secondary schools for ten hours a week. Pre- and post-measures of their interest level in becoming secondary teachers were made. Overall, graduate students decreased in their desire to become secondary teachers. The main reasons were (1) fellows wanted to work with higher-level mathematics and science; (2) fellows felt students were not behaved and unmotivated; (3) fellows did not view being a teacher as a career, but only as a job; and (4) fellows felt school systems had to do too many things that fellows did not want to do.

The number of students enrolled in K-12 education is rapidly increasing, while the number of teachers retiring is also at an all time high, and mathematics and science teachers leaving the field (e.g., switching careers) is an even more significant factor than retirement (Hussar, 1999; Ingersoll, 2004; National Commission on Teaching and America's Future, 2003; National Education Association, n.d.; National Science Board, 2006; Reys & Reys, 2004; Thomas, Mahlios, Friedman-Nimz, & O'Brien, 2005). In addition, only 60% of those trained to be teachers end up taking a teaching job (National Governor's Center for Best Practices, 2000). Thus, the yearly supply of new secondary mathematics and science teachers is not enough to meet the demand (Abell et al., 2006; National Commission on Mathematics and Science Teaching for the 21st Century, 2000; National Education Association, 2003; National Science Board, 2006). President Bush, in his State of the Union address in 2006, specifically called for the recruitment of more mathematics and science teachers by "bring[ing] 30,000 math and science professionals to teach in classrooms" (Bush, 2006).

State and national initiatives have attempted to increase the quantity of new secondary mathematics and science teachers (Darling-Hammond, 1998; National Commission on Mathematics and Science Teaching for the 21st Century, 2000; Reys & Reys, 2004; Selke & Fero, 2005; Thomas et al., 2005; U.S. Department of Education, 2004). Many of these initiatives, such as *Math for America* and *California Teach Science and Mathematics Initiative*, draw on mathematics and science majors or graduates who have not pursued teaching. These so called alternative licensure programs often offer financial incentives to draw people and then require a teaching commitment. Annually, approximately one-third of new teachers come from an alternative route (Feistritzer, 2007).

Besides attempting to increase the quantity of secondary mathematics and science teachers, state and national efforts are attempting to increase the quality of secondary mathematics and science teachers (U.S. Department of Education, 2004). *No Child Left Behind* (2001) requires that all mathematics and science teachers be "highly qualified." That is, they must hold at least a bachelor's degree, have competency in their subject matter, and hold a teaching license. People who hold bachelor's degrees in mathematics or science have two of these three requirements automatically met. In 2000, about 38% of all the teachers in the United States who taught mathematics did not have a major or minor in mathematics (Ingersoll, 2003). Science is more difficult to summarize, as someone might major in biology, for example, and teach physics. In life science, about 45% of teachers do not have a major or minor in the field, and nearly 60% of all teachers teaching physical science do not have a major or minor in the field (Ingersoll).

Both in quantity and quality, motivation exists to recruit mathematics and science graduates into secondary teaching. However, only a very small percent of people who have established careers in mathematics or science are drawn into alternative teaching licensure programs (Humphrey, Wechsler, & Hough, 2005). Recruiting candidates for these alternative licensure programs from mathematics and science graduate students would avoid attempting to remove mathematicians and scientists from established careers.

However, there would still need to be an incentive besides money. Most people who enter an alternative licensure program will have opportunity for a higher

salary once they are a teacher than they would have without the teaching license (Humphrey & Wechsler, 2005). This is not the case with mathematics and science graduates who usually have many prestigious and lucrative opportunities to consider (Abell et al., 2006). To draw mathematics and science people into teaching, one is going to have to appeal to something inside of the people or about the process of teaching and learning itself (Thomas et al., 2005).

People who have had some previous exposure to secondary education are fairly easily recruited into alternative licensure programs (Humphrey & Wechsler, 2005) because previous experience has helped them develop what they see as teaching skills and teaching would be a method of putting these skills to use (Dill, 1994; Feistritzer & Chester, 1996). In addition, the previous exposure seems to clarify for some people that there is a true need for quality teachers and some people are drawn to help fill the need (Feistritzer, 1990, 1992; Ludlow & Wienke, 1994; Stevens & Dial, 1993). In fact, undergraduate students who directly pursue secondary teaching as their major and future career choice, tend to do so for similar altruistic reasons or even intrinsic reasons (e.g., something about teaching itself), but rarely extrinsic reasons (Andrews & Hatch, 2002; Seymour & Hewitt, 1997; Young, 1995).

It seems then that a reasonable approach for increasing the quality and quantity of secondary mathematics and science teachers is to create a situation that gives mathematics and science graduate students intensive exposure to secondary education and follow this up with information on various alternative teaching licensure programs. This study adds to the research base by following just such an approach and examining the outcomes.

Research Questions

In the current study, graduate students in mathematics and science are placed in secondary mathematics or science classrooms for ten hours a week for one year. They are given financial incentives for accepting the placement. At the end of the year, the graduate students are given information on alternative teaching licensure programs, although the students are under no future obligations. Three questions are examined.

After completion of the year, does the interest level that these graduate students have in secondary teaching as a personal career increase, decrease, or remain unchanged?

If there is a change, what contributed to the change? In particular, were there qualities about secondary education, itself, that contributed to the change?

At the completion of the year, are any of the graduate students enough interested in secondary education to be interested in an alternative teaching licensure program?

Methods

Eight graduate students participated in the study. Two were in biology, three in geology, and three in mathematics. Seven of the eight were female. All eight were in their second of two years pursuing Master of Science degrees.

The eight graduate students spent ten hours a week in a secondary mathematics or science classroom. They were given $30,000 a year, plus $10,500 for educational expenses. Because their tuition and other expenses totaled slightly more than the allotted amount, they had to spend some of their $30,000 to meet their expenses. They did not hold a separate teaching assistant or research assistant position.

The funding for the graduate students came from a larger project. The National Science Foundation (NSF) has a program entitled Graduate Teaching Fellows in K-12 Education (GK12). In this program, NSF does not directly seek to encourage graduate students to become secondary mathematics or science teachers and there is no obligation on the graduate students that extends beyond the committed year.

The University of Minnesota Duluth (UMD), a comprehensive regional university located in the Midwest, received funding under the GK12 program in July 2007. Under UMD's proposal, up to ten graduate students seeking Master of Science degrees in mathematics, biology, or geology are selected to be "fellows". These fellows receive financial incentives to spend ten hours a week in a local school. In addition, fellows spend five hours a week doing preparation work. Each fellow is assigned a secondary teacher, who retains all teaching duties in the classroom. Fellows are to interact with secondary students and plan special projects that showcase their own graduate-level research in such a manner that secondary students can comprehend it.

The project's primary objectives are to:

1) Increase the interest, desire, skills and effectiveness of graduate fellows to teach and communicate science and mathematics knowledge with non-technical audiences and K-12 students.

2) Increase the knowledge, disciplinary specific skills, and confidence of K-12 teachers to effectively

teach science and mathematics.

3) Increase K-12 student interest and learning in science and mathematics.

The objectives are realized through the fellows' presence in the classrooms, as well as a summer workshop, academic year seminars, and special projects. The two-week summer workshop consists of a series of mini-lectures for the fellows on educational topics (e.g., classroom management, national mathematics and science standards, and technology in mathematics and science) and a week of the teachers and fellows making plans for the school year. The fellows are required to create two inquiry-based units during the academic year. Much of the planning time was necessary for the teachers to describe their particular needs. During the academic year, the fellows attend a bi-weekly seminar and the teachers join the fellows once a month, centered on an educational topic of the fellows' choice.

This study relies on data collected the first year of the project, in which nine graduate students were selected as fellows. The tenth position was left open in the hopes of recruiting a Native American graduate student (one of the involved secondary schools was on a reservation) to be a fellow. This spot was never filled. Selection was based on the academic record of the applicants during their bachelor degrees and their first year as graduate students. Eight of these nine fellows serve as the subjects in this study. One of the nine fellows selected had previously been a secondary mathematics teacher and intended to return to secondary mathematics teaching. He has not been included in the study.

After they were selected, each of the eight fellows was asked to give a pre-statement about his or her level of interest in teaching, as well as a numeric rating. Throughout the academic year, the researcher kept an observational log. At the end of the year, a structured interview of each fellow was conducted. The interview was designed to measure both their interest in pursing secondary teaching careers and their opinion on what aspects of the project lead to their change in interest (if there was a change in interest).

Pre-statements and Numeric Rating

Each of the eight fellows was asked to write a one or two page paper in which they were to describe their level of interest in secondary education. The paper was to include a statement of their level of interest in pursuing secondary science or mathematics teaching as a career, as well as any past experience with K-12 education, including degrees or certificates already held.

As part of a follow-up to the pre-statements and during the first week of the fellows being in the K-12 classrooms, each fellow was asked to give a numeric rating as to the level of negative or positive feelings toward the idea of becoming a secondary mathematics or science teacher. A -5 was to represent extreme negativity toward the idea, while a -3 was a moderate negative. Thus, a -4 was between extreme negative and moderately negative. A -1 represented a slight negative feeling, and a 0 was a neutral feeling. In a similar pattern, 1 represented a slight positive feeling, 3 a moderate positive, and 5 an extreme positive feeling.

Observational Log

The observational log consisted of an ongoing dairy after every contact that the researcher had with the fellows. These contacts included, but were not limited to, the academic year seminars and individual meetings with the fellows when they requested them. The observational log also included reflective and summary comments after reading statements by the fellows. The fellows were required to write reflective statements throughout the academic year.

Structured Interviews and Numeric Rating

At the end of the academic year, the eight fellows were asked to take part in a structured interview. This interview began by repeating the question regarding a numeric rating as to the level of negative or positive feelings toward the idea of becoming a secondary mathematics or science teacher. The fellows were then asked the series of questions given in the appendix.

Results

Pre-statements and Numeric Rating

The pre-statements by the fellows revealed some positive feelings toward secondary teaching. In fact, two of the eight fellows gave a score of 4 as to their interest in actually becoming secondary teachers (five was the highest possible score).

One of the fellows who gave a rating of 4 had experience and education in secondary teaching and actually held a mathematics teaching license, although she had never used it. She stated that she had "thought" of being a secondary teacher, but did not pursue it. Consideration was given to not including her in the analysis. However, because she had never been a secondary teacher and had no current plans to be a secondary teacher, and thus was not contributing to an increase in the quantity or quality of secondary teachers, it seemed that including her (as long as her results were clearly marked) in the study could be informative. We will use

the pseudonym of Karen for her. (A note to the reader: Table 1 is given later in the paper that gives pre- and post-scores for each fellow with pseudonyms. If the reader wishes to look ahead and/or recap what one is reading about each fellow, the table would allow one to do so.)

The second fellow who answered 4 on the scale of interest in secondary teaching directly stated that he hoped he would become a secondary science teacher, after earning his masters in science, although he had no previous experience with secondary teaching, nor any education toward secondary licensure. In fact, at the beginning of the year, he wanted to enter a program to obtain a license. We will use a pseudonym of Bruce for him.

Of the remaining six fellows, two gave a rating of 3 (pseudonyms Sue and Ruth), one gave a rating of 2 (pseudonym Molly), one gave a rating of 0 (pseudonym Sarah), one gave a rating of -1 (pseudonym Erica), and one gave a rating of -3 (pseudonym Laura) on their feelings about becoming a secondary teacher. Laura, Sarah, Molly, and Erica all saw teaching as a necessary component of most research positions, and said that it was important that they did a good job at that component, but research is what really mattered to them. Two of the six, Sarah and Erica, did state that the grant opportunity might allow them to understand if they should consider secondary teaching as a career. Ruth stated that she might grow in appreciation for secondary education through this process, but she stopped short of saying that she might want to become a secondary teacher herself. Sue said that she might try to find work in some type of science museum or other outreach, and that the grant experience would help her develop skills. She did not seem to consider that she herself might become a secondary science teacher. Finally, Molly said that she would one day "volunteer" time at secondary schools.

Considering all eight scores, the average rating was 1.5. Thus, before having the experience of being in the secondary classrooms, the fellows were leaning toward a mildly positive feeling about secondary teaching.

Observational Log

Within the first two weeks of being in the classroom, all eight fellows began to express great shock at the level of discipline that is required to maintain a secondary classroom. This was extremely unappealing to the fellows. Also very early in the year (observational notes record this within the first month) was the concern by all eight fellows that secondary students were unmotivated. These themes continued throughout the year.

At midpoint in the year, three of the fellows, Ruth, Molly, and Erica, expressed that they were depressed about themselves because they seemed to spend a lot of time yelling at students to get the secondary students attention. When the remaining five fellows heard this, they also agreed. At this point, the grant team brought in experts in education who gave seminars on classroom management and motivation.

Also at midpoint in the project, the project team asked the fellows to help in recruitment of fellows for next year. All eight fellows expressed that they thought there were more negatives to the experience than positives, and that if offered another year of the project, they would not do it. This surprised the grant team, if for no other reason than the salary of $30,000 per year was approximately three times the salary of a regular teaching or research assistant position at our university. One fellow, Ruth, went so far as to say, "I dread going into the classroom each day."

It should be noted that just because fellows would not repeat the grant experience does not mean they would not become secondary teachers. Whether this connection is true or not is explored in the structured interview. Throughout the academic year, the grant team tried to improve the grant experience, but did not attempt to influence fellows' interest levels in secondary teaching nor even directly ask them questions in that regard.

Structured Interviews

At the structured interview, the fellows were asked to again give a numeric rating as to their feelings about being a secondary teacher. Table 1 gives a summary of the pre-, post-, and change-scores. Two fellows went up in their scores, with one moving from a 0 to a 2, and one from a 3 to a 4. One fellow stayed the same, which was a -3. The remaining five fellows all went down.Two went from a 4 to a 2, one from a 3 to a -4, one from a 2 to a 1, and the final one from a -1 to a -2. The new average, although still positive, is down from 1.5 to .25. Another way of looking at these scores is to look at the change in pre- and post-scores (post minus pre), with the eight change scores being: -7, -2, -2, -1, -1, 0, 1, and 2, and with a mean change score of -1.25.

Each fellow was interviewed to see if they really thought their views had changed in the way the scores show, and if so, what aspects of teaching and/or the grant experience had contributed to the change. (The actual interview questions are in the appendix.)

Table 1
Pre- and Post-Scores

Pseudonym	Pre	Post	Change Score
		Positive Change Score	
Sarah	0	2	+2
Sue	3	4	+1
		Neutral Change Score	
Laura	-3	-3	0
		Negative Change Scores	
Karen	4	2	-2
Bruce	4	2	-2
Ruth	3	-4	-7
Molly	2	1	-1
Erica	-1	-2	-1

Looking first at the fellow whose score did not change, and reminding the reader that the score remained at -3, this fellow, Laura, stated clearly that there was nothing the grant could have done to change her mind about teaching. Yet, later she admits, "If I had an overwhelmingly positive experience in the classroom, I might have considered it, but I think part of it is just my lack of patience with certain students." Laura went on to talk a lot about students and student behavior. Apparently, Laura went into the grant experience expecting that she would feel impatient with students and that was her experience throughout the year. The following remark is a good summary of her thoughts: "I also feel like teaching is something where you either have a passion for it, and going through all of the crap is worth it, or you don't, and you shouldn't be in it. I don't want to become a teacher who constantly complains about her students, and just know myself well enough to seek other career paths." She also talked about her passion for statistics and mathematical modeling.

The two fellows that changed in a positive direction (0 to 2 and 3 to 4) had different reasons for increasing their desire. Sue changed from a 3 to a 4, but remarks that she only intended to "indicate that I am still interested in secondary teaching." She credited the grant experience for providing a "situation to let my interest mature". In particular, the grant experience "exposed me to that school culture again, very different from university." The following quote is representative of her thoughts.

> I appreciate the high school culture from staff to students. I like working with high school teachers. They have passion and have each learned some special things about students in order to be still working with them. Humor, timing, assertive, no-nonsense, caring, etc. I appreciate the enthusiasm, lack of enthusiasm, drama, and stage-of-life of the students.

Although she says she struggled, she enjoyed the knowledge and experience gained from being in a secondary environment, and even enjoyed "learning how to do teaching better." This fellow was at a charter school, and she admits that teachers and students might be different at a charter school. "Namely, I saw teachers who were able to teach within some of their specialized passions and students who responded to those specialized courses."

Sarah changed from a 0 to a 2 and states that the grant did allow her to "become more confident in my skills as a leader and communicator." In addition, she was very inspired by her teacher mentor, who she thought was very good at teaching. Finally, she mentioned some strong intrinsic motivation. She stated, "I felt that I was really a contributor and part of the students' school experience." That is, she could make a difference, and "I think I really enjoy when the students actually want to hear about what I will teach them, and when they truly grasp the concepts."

The five remaining fellows all lowered their interest in teaching. However, some lowered their interest more than others, and three lowered their interest, but remained on the positive side. We will examine those three first.

Karen lowered her score from 4 to 2. She remarked that she still had some interest in teaching, but she felt that the grant experience was very dependant on the particular teacher and classroom assigned. For example, she stated that her teacher used different discipline than she would. She also found the entire grant experience frustrating, because in her view some fellows did more work than others. She viewed the grant experience as a long student teaching experience, and did not think it was very representative of actual teaching. This particular fellow was the one who had a teaching license before entering the grant, but never choose to teach. She never gave a solid answer on why she did not want to teach before (she said things about wanting to pursue graduate work) and the grant experience apparently pushed her further away from wanting to teach. Perhaps if there had been less frustration for her, the grant experience may have worked better. Regardless, she was a bit of an oddity, already holding the current teaching license.

Another fellow who remained positive (lowered from 4 to 2) was Bruce, and he had stated at the beginning of the grant that he would definitely pursue a secondary teaching license. At the beginning of the grant, he had made arrangements to begin student teaching after the grant experience was over. Yet, sometime in the middle of the grant, he canceled those arrangements. He emphasized the "discipline and motivation issues, coupled with students' lack of knowledge" were large factors in his declined interest. He also mentioned that it was a deterrent for him that he would have to student teach and do other things to "prove my competence." If he had qualified for a position as a secondary teacher without doing those things, he may have pursued it. As it stood, he had lost interest.

The third fellow that remained positive was Molly, and she lowered her score from 2 to 1. She was the least able to articulate why her scores were what they were. She stated, "Working in a high school is not what I want to do. I am more interested in working with numbers and statistics." Although the grant experience "did not turn me off and I did learn a lot about secondary teaching that I didn't know, because I knew very little," she apparently learned she did not want to be a secondary teacher.

The remaining two, Ruth and Erica, lowered their scores and ended up in the negative direction. Both expressed gratefulness for having the grant experience, because it allowed them to know that they probably did not want to become secondary teachers. Ruth states that she had been pretty sure that at one point in her life she would be a secondary teacher, and now she is "happy that I didn't go ahead with teaching". Ruth went from a 3 to a -4. Her main reason was the main reason of all the fellows. She could not tolerate student behavior. "They are little energy suckers. They take up all your energy. I am burned out."

The other fellow, Erica, began negative and ended more negative (from -1 to -2). She immediately stated that the grant caused her to learn a lot of little details about secondary teaching that she did not "realize or think about before." She discussed that there is no real advancement in teaching, as one moves up the pay scale via experience. In addition, she says, " I really don't like the school system and how it works sometimes." Her elaboration on this was to describe low achieving students who take courses that they view as "gimme classes" and thus "expect it to be easy and the school expects all the students to pass even if it is just with a D-." In addition, she comments on student motivation, "I guess also it would wear on my nerves to have students that are not very excited about science as I am." She says that if she did become a teacher, she would work at teaching as hard as she could and feels that she would only last for two to three years at that pace, during which time she would be underpaid. Her concluding comment was that the grant opportunity "just opened up my eyes".

Limitations

Before moving on to conclusions, a note or two must be made on limitations of the study and the ability of the study to generalize. First, this is a small sample, for one year of a project. Funding considerations, especially giving each graduate student $30,000 per year, necessitates the small sample size per year. Repeating this study is certainly a good idea. The fact that the fellows were from different majors and went to different schools helps some with the sample size.

However, the larger concern here is that all eight fellows were from the same grant experience, and it is certainly possible that we did something very wrong with the running of the grant. Due to details that are unimportant and beyond our control, the fellows experienced frustrations at the beginning of the grant. For example, their pay was delayed for a month, and we had trouble with health insurance policies. The fellows had numerous opportunities to provide feedback to the grant team, and they did express frustrations with various things. The grant team was then quick to make im-

provements. In the end, it is our belief, based on feedback, that we did do a good enough job with the details of the grant experience that fellows were content with it all. In addition, comments in the interviews did not reveal that there was anything more the grant team could have done to make the fellows happier with the experience.

We believe the most significant concern is that all eight fellows were placed at schools with high Native American population, high free-and-reduced lunch population, and very high special education population. It is possible that had we placed students in elite, private schools, we would have had the opposite result. Sue was placed at a charter school, although it still had very high special education population. Yet, she had a move positive experience than other fellows. Nevertheless, we placed fellows in typical schools within driving distance of our university.

At this point, conclusions will have to be made for our fellows, under our circumstances, and repeat studies should be conducted. Yet, we emphasize that our fellows were at typical schools. This is important in the following sense. If we were successful in creating future teachers, they would most likely find work in typical schools. If we had placed our fellows in "special" schools and they went into teaching, it is possible that they would not have stayed with teaching, once they saw what a more typical experience was. Although we could have manipulated circumstances to create a more positive overall result, the experience as it stands did expose fellows to secondary teaching.

Conclusions

Research suggests that if one could appeal to something inside of people or about the process of teaching and learning itself, then one might draw current mathematics and science graduate students into secondary teaching (Thomas et al., 2005). This study exposed mathematics and science graduate students to secondary teaching in order to appeal to something inside them or about the secondary teaching itself. Unfortunately, it appears that the exact opposite occurred with this set of students.

Overall, the interest level that the fellows had in secondary teaching as a personal career decreased during the grant experience. Not a single graduate student was interested enough in secondary teaching to even take the material offered on alternative teaching licensure programs. Although each fellow was examined individually, four common reasons prevailed. The four reasons are (1) fellows wanted to work with higher-level mathematics and science; (2) fellows felt students were not behaved and unmotivated; (3) fellows did not view being a teacher as a career, but only as a job; and (4) fellows felt school systems had to do too many things that fellows did not want to do.

Fellows had a strong desire to work with content beyond the content allowed at a secondary level. Some fellows wanted to pursue academic careers at universities. All the fellows wanted to have on-going research projects that would go beyond what they would do as secondary teachers. In fact, no one felt that research projects fit particularly well in the secondary level.

The number one reason, however, for not wanting to pursue a teaching career was about the poor behavior and lack of motivation of secondary students. Simply put, the fellows were shocked at how secondary students behaved and found it just plain depressing.

Another reason intrinsic to education was that the job itself did not seem to be much of a career. For example, there is no system of advancement, beyond a higher salary for more years worked. The fellows might have reacted better to a merit system. Another issue is the teaching license. Some of the fellows saw the educational process as a lot of busy work or hoop jumping. Paying teachers more and having opportunity for advancement (e.g., secondary teachers could have ranks such as professors do) may work to turn teaching into more of a career.

Finally, the last reason intrinsic to secondary teaching was that school systems have certain policies that the fellows did not like. For example, the fellows believed that teachers were directed to pass all students. There was also a lot of wasted time, in the eyes of the fellows. Secondary students went to school gatherings and too much time was used up on testing. School systems could work to eliminate some of the nonessential things and spend time on discipline issues. Of course, special grants and projects, such as this one, attempt to motivate and interest students in mathematics and science.

There was one exception to the rather dismal results of the grant year, and that was the fellow who used words that nearly verbatim supported our hypothesis. She felt good at teaching and that her teaching of students made a difference in their lives. This made the idea of being a secondary teacher attractive to her. This was Sarah.

Graduate students in mathematics and science are a possible source to fulfill the increasingly urgent need

for mathematics and science teachers. However, this study reveals that it might be difficult to recruit from this pool. The concerns that these graduate students have with becoming secondary teachers are not easily answered. For example, the graduate students in this study wanted to work with higher-level mathematics. How is one to put higher-level mathematics into secondary teaching? Even if something radical was done, such as have teachers work part-time teaching and part-time as research scientists, this may not satisfy the fellows. For, in reality, it probably is not just that fellows want to work with higher-level mathematics and science, but fellows do not want to work with lower-level mathematics!

When all is said and done, it might very well be true what one of the fellows said. One either has a passion for teaching or one does not. In that case, our results may not be negative at all. After exposure to secondary teaching, many of the fellows did not want to pursue secondary teaching. Perhaps they did not have a passion for it. However, two of our fellows did increase in their scores and a new group of fellows may contain graduate students with more intrinsic passion. The best conclusion seems to be that we might continue to look toward graduate students for a future source of secondary mathematics and science teachers, but we should continue to look for other sources, as well. This study would suggest that society is not going to be able to solve its lack of science and mathematics teacher crisis with graduate students alone.

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Appendix

1. You have given a rating of interest that is
{lower than, higher than, the same as}
the one you gave at the beginning of the year. Do you feel it is accurate that your interest level has {dropped, risen, is the same}?

2. Can you pinpoint some reasons that explain your change (or lack of change) in interest level? That is, what about secondary teaching makes you as interested as you are? And what about secondary teaching prevents you from being more interested?

3. Is there something that could change about secondary teaching that would increase your interest level?

4. What did you learn about secondary teaching during this past year that you didn't already know?

5. What happened during this grant experience that you feel influenced your interest level in secondary teaching?

6. If the grant could be changed in some manner that would result in graduate students becoming more interested in secondary teaching, what would those changes be?

7. I have information about alternative teaching licensure programs. Are you interested in possibly pursuing a teaching license?

A Cross Discipline Study of Reformed Teaching by University Science and Mathematics Faculty

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Researchers observed 28 university faculty in graduate and undergraduate science and mathematics courses in a three-year, longitudinal study of teaching. Subjects were selected from five higher education institutions in the state where faculty had a two- to five-year association with a reform-based NSF professional development program. Observer field notes and a researcher-designed observation instrument were used to describe and compare teaching practices. The participants in this study taught science and mathematics content courses for majors, non-majors, as well as education majors. Our observation method created a descriptive profile that enabled comparisons across a variety of teaching contexts. The main results showed that the faculty lacked practices that supported development of divergent thinking, conceptual thinking, and metacognitive thinking skills. Observed differences in the profiles of instruction included greater emphasis on real-world connections in science and greater use of cooperative problem solving in mathematics. A case study of a large lecture course describes reformed teaching practices in even the most challenging setting.

What is the effect on the teaching practices of a new high school teacher of all those years in college science and mathematics courses? Borko and Putnam (1996) called this the extended apprenticeship of a teacher. The NSF broadly addressed this issue by funding 35 large-scale, five-year Collaboratives for Excellence in the Preparation of Teachers (CEPT) in as many states from 1993 through 2002. The CEPT program was motivated by long-standing concerns over the quality of teaching in college level science and mathematics (National Research Council [NRC], 1996; NRC, 1999; National Science Foundation [NSF], 1996) and the national need to address the attrition of students from these majors. Before answering the question directly the authors, working through the Oregon Collaborative for Excellence in the Preparation of Teachers (OCEPT), collected data on university faculty who participated in some aspect of OCEPT and were identified by prospective teachers as previous instructors. These data represent what we have learned about the teaching practices of the university science and mathematics faculty.

K-12 teachers have nine months to incorporate reform-based strategies in their classrooms where college faculty have at most four months in a semester based system. Both school teachers (Manouchehri, Azita, & Goodman, 1998) and university faculty (Matney, Hurtado, & Ziskin, 1999) who are receptive to reform guidelines, view *time* as a critical challenge to making changes. Another challenge is that the principles and standards contained in reform documents are often described in recitation-size classrooms. Classes with over 100 students are quite common on most college and university campuses and especially in research oriented institutions. How do instructors apply reform guidelines in larger classrooms? What benefits, if any, could this system accrue for undergraduate students who take courses from faculty who are committed to reform standards? These questions motivated this project describing efforts at reforming collegiate teaching.

Conceptual Framework

There is motivation to analyze collegiate teaching in science and mathematics from both inside and outside the college campus. Reports from outside, present data that suggest the educational experience in college is

not compelling. The Higher Education Research Institute annually conducts a survey of first year students. The 2005 administration was conducted in 141 four-year colleges and universities around the country (Hurtado et al., 2007). Students indicated they were "satisfied" or "very satisfied" with the quality of instruction (71.8%). However, looking a bit deeper 43.5% indicated that they "frequently felt bored in class" and only 24.1% marked that they "frequently felt that your courses inspired you to think in new ways." This survey suggests that students are "satisfied" with a passive role in college classes.

Student passivity towards their education may be behind concerns about the capabilities of students who leave with degrees and enter the workforce without skills critical for high performance in competitive jobs (Baer, Cook, & Baldi, 2006; National Center on Education and the Economy, 2007; Resnick & Wirt, 1996). The large number of students who enter post-secondary education but do not complete a degree is indirect evidence that students simply do not see the point of this educational experience. Estimates of the overall college completion rate are as low as 50% for both two- and four-year degrees and certificates (Silverberg, Warner, Fong, & Goodwin, 2004).

Student dissatisfaction with science and math courses in particular does not appear to be explained by ability or effort. Complaints about teaching quality are as similar for those who leave the major as for those who stay (Seymore & Hewitt, 1997). This issue takes on greater importance when we consider teaching courses for non-majors. Vision 2 of the Committee on Undergraduate Science Education of the National Research Council (NRC, 1999) states: "SME&T [science, mathematics, engineering, & technology] will become an integral part of the curriculum for all undergraduate students through required introductory courses that engage all students in SME&T and their connections to society and the human condition" (p. 3). Attempts to increase the amount of SMET courses in the curriculum will be counter productive if student experience is negative. For example, studies of student epistemologies of science in introductory physics courses at six different institutions using various instructional techniques show that student views of science become less sophisticated after the course than before (Redish, Saul, & Steinberg, 1998).

There is also motivation to analyze collegiate teaching in science and mathematics from inside college campuses. During the last decade, an increasing number of institutions of higher education in general and research universities in particular have created teaching and learning centers (POD Network, 2005). The purposes of these centers include improving instruction in classrooms intended to impact students early in their college careers. The "Preparing Future Faculty Initiative" involved 43 doctoral degree granting institutions and over 250 partner institutions in a program that provided professional development to doctoral students. The multidisciplinary program helped prepare these future faculty for the full range of responsibilities with a focus on teaching. Despite successes in the program, evaluators acknowledged the ongoing tension between research and teaching in the research universities (Goldsmith, Haviland, Dailey, & Wiley, 2004). Further, they echoed the goals of the NSF collaboratives by emphasizing the potential impact of improved teaching in science and mathematics on future K-12 teachers (Goldsmith et al.). Since 2001, the Mathematics Association of America (MAA) has operated Professional Enhancement Programs for mathematicians in all stages of their careers across a variety of topics including teaching and course design. Project NExT (New Experiences in Teaching) is another MAA program aimed at faculty in their first or second year. These discipline-based and multi-disciplinary programs are tapping a growing interest inside higher education institutions for examining the nature and effectiveness of instruction. Support of online resources reflects the interest at the professorial level for improving instruction. The National Science Teachers Association has opened a section of its web site for "The College Science Classroom" (National Science Teachers Association [NSTA], 2005). The Stanford Center for Teaching and Learning has created "Tomorrow's Professor Listserv." The Stanford Center seeks to foster discussion and sharing of ideas about teaching and learning among its over 21,000 subscribers at over 600 institutions and organizations in over 108 countries around the world (Stanford Center for Teaching and Learning, 2005).

As resources for improving collegiate teaching increase, so does our need to understand how change in the college classroom takes place. Gess-Newsome, Southerland, Johnston, and Woodbury (2003) analyzed the reform efforts of three science faculty in the delivery of a single course and concluded that providing time through grant support needed to be coupled with faculty determination to overcome the systemic obstacles to change in teaching practices (see also Boyer

Commission, 1998). Akerson, Medina, and Wang (2002) described how one engineering professor discovered to his surprise the amount of time and resources required to support changes in teaching. In addition, he observed the importance of support systems that offer guidance and help faculty manage the inherent discomfort of change. Understanding the nature of change through research gives greater legitimacy for innovation in teaching. Boyer (1990) describes four scholarships: discovery, integration, application, and teaching fostering an understanding that knowledge accrues from research, through synthesis, and from teaching. Centers for teaching and learning in higher education support these kinds of knowledge growth and give a voice to and venue for new conceptions of scholarship.

The research driving changes in college teaching derive from basic research on learning (Bransford, Brown, & Cocking, 2000). This research has shown the value of eliciting student conceptions, providing opportunities to socially construct new points of view, and reasoning from direct experiences (Crouch, & Mazur, 2001; Elby 2001; Redish, 1994; Redish et al., 1998; Reif & Larkin, 1991; Zeilik, Schau, & Mattern, 1999). This research has informed the work of the current study and others (see Swada et al., 2002).

Faculty uninformed by the body of research driving instructional change, examples of which are cited above, face great difficulties in creating a sustaining change. Henderson (2005) studied a case of teaching reform by a tenured member of a physics faculty at a research university. This physics professor entered the task with exaggerated expectations of a personal model of instruction derived from experience and uninformed by relevant research on instruction. This led to an underestimation of the time, effort, and need for ongoing revision that followed, resulting in little lasting reform and little personal reward for his efforts. Even with knowledge of background research Parsons (2001) found that personal reflection and study was necessary. She examined her own teaching of a science methods course for elementary teachers. Her protocol for guiding in-depth reflection on her own beliefs and video and audio recording of her teaching revealed inconsistencies between her intentions and her practice. She frankly comments that "As a consequence of the philosophy-practice discontinuity, the attainment of my goal, student understanding of the instrumentalist view of science and scientific knowledge was compromised" (p. 6). A larger study involved 30 college instructors of mathematics and revealed similar results. LaBerge, Sons, and Zollman (1999) used interviews and a survey to examine instructor awareness of educational reform goals and beliefs about the efficacy of those goals. They found that instructors expressed views consistent with reform goals but that these views were not translated into practice as assessed through an interview. The general lack of consistency between views of reform teaching and teaching practice motivated our close examination of teaching and faculty descriptions of teaching.

This study examined the instruction of 28 college and university faculty and broadened the analysis in our earlier work in this area (Wainwright, Morrell, Flick, & Schepige, 2004). The research questions were (a) What kinds of reform-based teaching practices are being used by university faculty across diverse settings? and (b) What are implications that will inform university faculty interested in changing their own teaching?

Sample

We targeted faculty who were already interested in improving their own teaching and currently involved in implementing new practices. This met a criteria stated by other researchers that sustained effort will derive from faculty who are dissatisfied with current practice and motivated to change. Examining faculty actively creating and initiating change would yield the most meaningful data for future research on reforming college teaching. We identified our 28 subjects through their participation in OCEPT (see Table 1). OCEPT provided experiences and support for participating faculty, referred to as "faculty fellows," to encourage the use of teaching practices recommended in science and mathematics education research.

Subjects were selected in a process designed to support the larger objective of the NSF CEPT program to study the relationship between faculty teaching practices and the teaching practices of beginning teachers who have taken their courses. Faculty in this study spent from one to three years engaged in OCEPT activities. Over its five-year history, OCEPT facilitated activities to broaden faculty knowledge of science and mathematics reform in curriculum and instruction. The focal activity was an extended faculty workshop during the summer. The first summer workshop was two weeks long but was reduced to one week because of faculty feedback concerning time constraints. Additional workshop time was scheduled during the aca-

Table 1
Faculty Fellows by Subject and Institution

Institution*	Science	Math	Totals
Very High Research (VHR-PUB)	2	5	7
High Research (VH-PUB)	0	1	1
Doctoral Research (DR/Lg-PUB)	3	3	6
Doctoral Research (DR-PRVT)	0	1	1
Masters – Medium Prog. (M/Med-PRVT)	3	2	5
Masters – (M/Lg-PUB)	5	3	8
Totals	13	15	28

* Institutions described as either public or private along with the Carnegie Foundation Basic Classifications (http://www.carnegiefoundation.org/classifications/index.asp?key=791)

demic year often organized with a subject-matter focus. Subject-matter groups attained their own identity and some, such as physics, scheduled their own meetings outside of the OCEPT schedule. Workshop activities included leadership training to leverage the impact of OCEPT on home departments through faculty run seminars and colloquia.

An explicit objective of OCEPT was to promote recognition of those students in science and mathematics classes who were planning to become teachers. NSF intended CEPT to foster a culture of teaching improvement that would ultimately influence future teachers. In support of this goal, faculty were instructed in the process of becoming a licensed teacher in the state of Oregon. This included information about K-12 licensing requirements, the structure of the Oregon Department of Education with respect to licensing, teacher education programs in OCEPT institutions, research-based teaching strategies, state science and mathematics standards and state required assessments. K-12 teachers modeled teaching strategies as a part of this educational process for college faculty.

Faculty were recruited who were known for their innovative teaching methods. Those faculty modeled teaching techniques and engage their peers in the experience of "reformed" teaching. Discussions followed that unpacked the experiences for possible use in other courses and in different types of colleges. Faculty also compared college teaching to K-12 teaching and reflected on the changing expectations of in-coming freshmen. Teaching experiences included but were not limited to methods for (a) engaging a class in hands-on experiences, (b) conducting whole-class and small-group discussions, and (c) taking field trips and utilizing other resources outside the classroom.

Recruitment of faculty was an ongoing process. Faculty were supported with a $3000 stipend to pay for materials, or graduate student time, or for summer support to revise course content or pedagogy. This amount of support was not enough to guarantee long-term involvement. Some faculty attended OCEPT for a couple of activities in one year while others continued for up to three years. In the current study, we have data on faculty that span from one to three years' worth of observation. The length of observation time was not related to faculty time in OCEPT. Overall, OCEPT was not so much a "treatment" as it was a focal point for promoting change for interested faculty. OCEPT provided an important opportunity to observe faculty actively focusing on improving instruction in the context of current research-based reform efforts. For the rest of this paper, the faculty who were subjects of this study will be referred to as "fellows," reflecting their selection from OCEPT.

Methods

The research protocol involved making three observations of each fellow within a given course. Researchers in this study designed the Oregon Teaching Observation Protocol (OTOP) and related interview protocol to provide a common metric across classrooms and instructors for comparing and contrasting. Observers in this study rated the ten OTOP Items (see Appendix) at the end of each class observation and took descriptive field notes during the observation. Field notes strengthened the validity of observational data by providing specific examples that supported OTOP ratings that observers discussed at periodic calibration meetings. The OTOP was initially validated by two panels of experienced science and mathematics

educators and checked for reliability across a range of classrooms (Wainwright, Flick, & Morrell, 2003). Observers in this study were four faculty from the participating institutions and three doctoral students from two of the research universities. All four faculty had experience in teaching middle and/or high school science and had taught science education and lower division science at the college level. Two of the three doctoral students had experience in teaching pre-college science and had been a teaching assistant in science education courses. The third doctoral student had experience teaching mathematics at the pre-college level and taught lower division mathematics at his university. Observer experience was matched to either science or mathematics classroom content. All of the doctoral students have subsequently completed the PhD degree in science or mathematics education.

The observers were initially trained in the use of OTOP using selected videotapes of classroom teaching. We paired more experienced faculty with less experienced doctoral students for calibrating observations by discussing similar and dissimilar ratings. All seven of the research team met at yearly intervals to calibrate judgments when using the instrument. At these meetings, we discussed interim results from observations of different kinds of classrooms. We compared OTOP ratings from large lecture classes with those of average to small sized classes. We discussed what seemed reasonable given observer descriptions of these diverse settings and reflected on a common understanding of what the OTOP ratings in various categories meant.

Each fellow was asked to supply the research team with his class schedule. Most of the fellows gave the team unlimited access for classroom observations. This meant observed lessons were delivered without the explicit expectation that they would be observed. Each fellow was observed teaching at least three classes in a given term. After the series of observations, each fellow was individually interviewed using a semi-structured interview protocol based on the OTOP called the Oregon Teacher Interview Protocol (OTIP) (see Appendix). The OTIP was reviewed for content validity based on the OTOP instrument by the research team. Typically, the interviews lasted about 30 minutes. Forty-one interviews were audio taped and transcribed for analysis. We collected 123 sets of observational field notes and completed OTOP instruments over the three-year period (see Table 2).

Data analysis developed in two phases. Phase one dealt with the analysis of the OTOP ratings. Phase two compared OTOP analysis with the analysis of faculty fellow interviews.

Quantitative Analysis of Data

Kruskal-Wallis H Test was used to analyze ordinal data gathered under the 10 OTOP categories as independent variables. The statistical procedure was used on the median scores recorded for each faculty fellow on each of the OTOP categories in any given year. This meant that if a faculty fellow was observed 3 times in a year, then, for each OTOP Item, only the median score for that year appeared in the analyzed data file (Thompson, 2006, p. 37). For fellows who participated in the study for two or more years, one additional row of data was included in the data file for each additional year; the level of significance for all statistical tests was set to 0.05. The OTOP instrument yielded a Cronbach Alpha value of 0.835. The null hypothesis presumed there was no difference between teaching practices of the fellows with respect to the subject taught, class-

Table 2
Number of Observed Courses by Subject and Institution

Institution*	Science	Math	Totals
Very High Research (VHR-PUB)	4	7	11
High Research (VH-PUB)	0	1	1
Doctoral Research (DR/Lg-PUB)	4	7	11
Doctoral Research (DR-PRVT)	0	1	1
Masters – Medium Prog. (M/Med-PRVT)	3	4	7
Masters – (M/Lg-PUB)	5	5	10
Totals	16	25	41

* Institutions described as either public or private along with the Carnegie Foundation Basic Classifications (http://www.carnegiefoundation.org/classifications/index.asp?key=791)

Table 3
Statistical Significance Measures from Kruskal-Wallis Analyses of the Median Annual OTOP Ratings for the Faculty Fellows Based on Separate Comparisons with Respect to Subject, Classroom Size, and Institution Type

OTOP Item	Comparison by Subject	Comparison by Size	Comparison by Institution
1. Values Modes of Investigation	$p<.008$*	$p<.031$*	$p<.649$
2. Reflects on Learning	$p<.058$	$p<.061$	$p<.036$*
3. Collaborative working relationships	$p<.002$**	$p<.002$**	$p<.513$
4. Values challenging ideas	$p<.009$*	$p<.007$*	$p<.976$
5. Probes existing knowledge	$p<.156$	$p<.268$	$p<.027$
6. Promotes conceptual understanding	$p<.553$	$p<.408$	$p<.098$
7. Encourages conjecture, interpretation	$p<.100$	$p<.024$*	$p<.693$
8. Cross curricular connections	$p<.002$**	$p<.614$	$p<.313$
9. Pedagogical content knowledge	$p<.618$	$p<.326$	$p<.115$
10. Uses multiple representations	$p<.222$	$p<.350$	$p<.050$*

* significant at $p < .05$
** Indicates significance with a Bonferroni correction $p < .005$

room size, or institution type.

Because 10 independent Kruskal-Wallis tests were conducted, one for each item, significance shown in Table 3 reflects a Bonferroni correction. Of the three significant differences identified in this manner, two are with respect to subject and one with respect to class size. However, class size differences are suspect in that there were only two different large classes (100) and four medium (40) in the sample (see Table 4). That leaves 32 small classes. Average mean ranks were used to determine the direction of the difference.

The following discussion of the quantitative results focuses only on the question: *What practices do faculty demonstrate and how do these practices differ between science and mathematics classrooms?* Mathematics faculty used collaborative settings more than the science faculty (Item 3, $p < 0.002$). These strategies involved organizing students for group work and providing clear outcomes from grouping arrangements. In other words, to be rated "frequent" in this category, it was not enough to simply place students in small groups for discussion without an explicit indication of purpose and procedures. Science faculty demonstrated significantly more frequent strategies for connecting the topics they discussed in class to real-world situations or other curricular areas (Item 8, $p < 0.002$). Observations of these strategies include both student- and instructor-generated applications. It is possible, though not common, to calculate a confidence interval for non-parametric tests of significance. Using an iterative technique of slightly varying the value of the null value, we performed a sequence of two sample tests at the 0.05 level. Those values that are not rejected become part of a 95% confidence interval (Ramsey & Schafer, 2002). Using this technique the confidence interval for each of the two effects (above) was ± 1 on the scale of 0 to 4.

Ignoring the Bonferroni correction for the moment, our attention is drawn to mathematics instruction that may have favored practices acknowledging student-generated approaches to investigation and problem solving (Item 1). This item involves observations of encouragement of discussion of alternative explanations and the presentation of open-ended problems. Possible student responses to these strategies would be student-posed questions and suggestions for relevant means for investigation. Another possible contrast is a strategy in mathematics instruction that challenged student ideas (Item 4) through questions or challenging problems. Observations of these strategies included the instructor taking a non-judgmental stance in fielding student input, soliciting further input from other students, and students providing evidence-based arguments or examples and counter-examples.

The above results are indicators for further study where contrasts in instruction by subject matter high-

light areas recommended by research but not currently utilized. The limitations of our quantitative data also raise questions as to how a given research-based strategy may work differently across subject matter areas or in different class formats, for example lecture versus recitation. To further examine these questions, we conducted in-depth interviews with the instructors. The following qualitative data provides some support for the above results and deepens understanding of other categories of the OTOP instrument.

Qualitative Analysis of Data

Field notes and the faculty fellows' responses to interview questions constitute the qualitative data. We provide the following as an example of how individual faculty and year of observation were identified: *ff.VHR-PUB.mth.E.I.* The identifier is decoded as follows: Faculty fellow (ff) (as opposed to a teacher), type of institution (*VHR-PUB*: very-high research, public, see Table 1), *mth*: subject matter, E: instructor identifier, and I: observation year one.

The quantitative findings for mathematics and science instruction were confirmed. Mathematics faculty discussed the use of more open-ended questions in class and encouraged use of alternative problem solving strategies more often than science fellows (Item 1). One mathematics fellow stated, "I ask questions that were vague enough that you could actually maybe try to think of your own hypothesis about something" (ff.VHR-PUB.mth.E.I). Observation of another mathematics faculty resulted in the following field note: "He also is comfortable with his subject matter and situations where the 'correct' answer is not found. Rather than being flustered by an error, Dr. D. often utilized the situations for problem solving" (ff.M/Med-PRVT.mth.D.I). Mathematics faculty were more vocal about collaborative activities (Item 3) as well as about pressing for constructive criticism, and challenged student ideas (Item 4) as indicated in the following excerpt from field notes:

Her lesson included brief introduction, main students' problem solving activities, then students' presentations of their solutions by turns. Based on their questions that they had already done at home individually, students were much engaged in solving problems with arguments, evidence, and critiques. A few questions assigned to students in groups were explored with all different interpretations (ff.VHR-PUB.mth.H.I).

The field notes from another observer read "The class session was designated as 'peer-review' [and] students were to critically review a partner's work on a portfolio assignment. Hence, there was a lot of student-to-student discussion. The discussions included critique and explanations among pairs" (ff.DR/Lg-PUB.mth.Burt.II). Such observations were associated with other explicit statements to students that guided the purpose and procedures for small group interactions.

The quantitative analysis showed that science instructors made more frequent connections to other curricular material or to real-world situations. Sometimes there were obvious connections; "Again, if you are looking at real world connections, animal behavior is great, because people can think about their pets and why their pets are doing different things. So that is kind of easy" (ff.M/Lg-PUB.sci.Hab.I). However, to make the strategy of real-world connections a regular part of science instruction required strategic effort on the part of the instructor as illustrated by this more extended example:

"When things happen nationally, we were waiting to see about Iraq, when that happens, we have a whole lecture planned on the flora and fauna of Iraq. So we can be more flexible, I think, in some cases. Like when anthrax, we were able to do a lecture on anthrax, and in the spring term, we will have small pox. So there are some things that are not just content (curricular) related. It is like, this is relevant to your life, is a big thing. And that is not really content (curricular) as much as it is just kind of a realization in general that you need this" (ff.VHR-PUB.sci.Bl.II).

The above findings triangulate well with the quantitative outcomes. However, additional findings surfaced in the qualitative data. Conceptual thinking (Item 6) and divergent thinking (Item 7) strategies were observed infrequently across all classrooms. The following examples capture two noteworthy positive examples to make a point about fostering conceptual thinking in contrast with divergent criticism. The following are field notes from a 200 level mathematics course for elementary teachers:

"Conceptual thinking Score 3: ...students needed to use basic concepts such as some ratio properties found in right triangles and circles. They used those basic concepts to prove the given (trigonometric) ratios, which was more complicated [than examples]. Divergent thinking Score Not Observed: Even though [the instructor] gave chances to think about the problem individually, those were not for providing divergent ideas in solving problems" (ff.VH-

Table 4
Class Size of Observed Courses

	Small ($n < 40$)	Medium ($40 \leq n < 100$)	Large ($n \geq 100$)	Total
Year I	10	1	1	12
Year II	9	1	2	12
Year III	13	2	2	17
Total	32	4	5	41

Table 5
Number of Classes Observed by Institutional Type

	Public Institutions	Private Institutions
Year I	8	4
Year II	11	1
Year III	14	3

PUB.mth.L.III).

The description of these categories required the observer to assess when the instructor was intending to get students to extend an idea and build on other ideas (Conceptual, Item 6) or to challenge and critique the thinking of others or the text (Divergent, Item 7). The fellow's intentions to extend and relate an idea may not involve challenging and critiquing the idea as in the above example. However, sometimes an instructor who fosters conceptual thinking may follow with challenging and critiquing ideas. Observations of a science fellow fit this pattern. He led the extension of an idea in weathering and erosion to more examples helping students build the concept. Students expressing a critique of the teacher's concept followed.

"Item 5, Score 3: He checked students' prior knowledge through questions and helped them build new concepts based on their prior knowledge. There were different responses from students but no chance to respond to each other.

"Item 6, Score 3: no higher-level questions but (the instructor) extended content to the broader one. He used two basic concepts of property in weathering and erosion to explain the natural phenomenon.

"Item 6, Score 4: There was chance of inquiry based on students' observations and interpretations. Some students criticized teacher's idea, but not the ideas of other students" (ff.DR/Lg-PUB.sci.T.II).

Fostering conceptual thinking and criticism in the classroom is time intensive and requires students to be prepared for this level of cognitive engagement. Further, the instructor has to be willing to view his or her content area as problematic, recognizing that real problems reveal portions of the content that are "ill-structured" and require that students and instructor talk about alternative views and criticize each other. This runs counter to traditional approaches to subject matter (Resnick, 1988).

We assumed that any reformed-based observation protocol would show large lecture settings do not afford the opportunity for high levels of student-teacher interactions and would receive lower evaluations. Due to small numbers of large classes, our data do not allow quantitative comparisons based on class size (see Table 4). Contrasts between public and private institutions were also made problematic due to small numbers (see Table 5. However, we found that class size did not eliminate novel and pervasive applications of some reform strategies with interesting adaptations that can inform reform-minded faculty.

Our analysis will focus on a case study of one instructor who ran a large lecture-based course. We compare his profile with that of two other smaller classes with comments about affordances and constraints of different class formats (see Table 6). The instructor, Dr. Nash, holds a Ph.D. in inorganic chemistry and an M.S. in science education. He holds an instructor position at VHR-PUB of 19,000 students. He has held this position for five years. We made nine observations of his lectures for CHEM 121 for which he was the lead instructor over the three-year period. The course had four sections of about 250 students each for a total enrollment of 900, mostly freshmen and sophomores. He gave his 50-minute lectures in a theater-style room

Table 6

Comparison of OTOP Profiles for Instruction in a Large Lecture Class Compared to Instruction in Two Small Classes

Item	Description OTOP Categories	Median Ranks		
		Nash (N = 250)	Roberts (N = 12)	Hurley (N = 26)
1	Habits of Mind	2	2	3
2	Metacognition	3	2	3.5
3	Collaboration	0	2	4
4	Rigorously Challenged Ideas	1	2.5	4
5	Preconceptions/Misconceptions	3	2.5	3.5
6	Conceptual Thinking	3	2.5	3.5
7	Divergent Thinking	1	2.5	4
8	Interdisciplinary Connections	2	3	1
9	Predogogical Content Knowledge	4	4	4
10	Multiple Representation	4	2	2

with about 300 fixed seats. He used an overhead projector and sliding chalkboards behind a long demonstration table. The large majority of students were non-majors.

The Lecture Class of Dr. Nash

Upon entering Dr. Nash's lecture room, you immediately observe his energy and approachable demeanor. He is busy putting notes on the board and arranging materials on the demonstration table. However, he is also looking up at students, saying hello, and conveying an explicit welcome to this class. Dr. Nash works on developing a rapport with students, aware that many students harbor high levels of anxiety toward the study of chemistry or any science or math subject. He tells students that if they work with him, he will get them through. This is not a blanket commitment to passing everyone; it is a description of a partnership. It is an expression of his overt interest in teaching as much chemistry to as many students as possible. His orientation is to keep students in the course and not weed them out. During an interview he commented that a single paragraph about "chemistry is really difficult and this class weeds out students" placed in the syllabus and stated aloud during lecture could easily result in a large portion of the class dropping out or failing. Instead, the atmosphere of support creates a very different point of view. Says Dr. Nash, "It is interesting how I've come to think about how far you can push students. You could probably make them do far more in this 10-week term than they would have ever imagined at the beginning." He makes their progress explicit by having students review their current understanding of portions of the text covered weeks earlier.

In lecture, Dr. Nash poses one of his many questions, and pauses, as he always does, for an answer. Looking toward the back at the top of the lecture theater, he says, "You are awfully quiet back there." To which a student responds, "It's Monday." Laughter and additional comments come from around the room. Students are alert and it seems most are engaged. He uses humor and distributes his attention around the 300-seat theater. Questioning is a common rhetorical device of lecturers but he applies this tool with a focused purpose to solicit involvement. He uses eye contact to encourage participation and to communicate the expectation of a response. He is aware that responses will come from only a small group of students unless he overtly expresses an invitation to participate. He described one strategy in the following way, "I do the eye contract with everybody during the period. But also try to pick on a few people. I won't call them by name, but I will single out a group for the first 10 minutes and focus on them. It is kind of like giving them the eyebrow. Come on, I know (you can be) responsive." Students pick up on this behavior and know what is happening. They are alert. He always repeats questions for the sake of the 254 students, but he never uses a student's name. He does not say, for instance, "Alicia asked…" If the students hear the names of the few students who are most willing to respond, then they may get the rep-

utation of being a favorite. He thinks that students are more likely to speak up if they can remain somewhat anonymous. Since he has responsibility for the year-long course sequence, he has noticed that students are much more likely to speak up in the spring than they are in the fall. They learn the expectations and respond. It is effective. Records show fewer students drop out of this course under his direction.

It is uncommon for students in a large lecture to have questions posed for which they are expected to give a response. Clearly, the responsibility for responding is less than it would be in a small recitation section, but Dr. Nash uses a variety of strategies to communicate his expectations. He structures every class around a problem and as content is developed, he asks students for ideas. One strategy is to simply wait for an answer and they know that he will wait until someone speaks up. Dr. Nash observes, "If that leads to a little uncomfortableness, that's okay, because then they feel this isn't right, somebody, even myself, better speak up." To direct attention to important content and promote student involvement, he will overtly plant a question. "...I'll even joke with them, and say, 'Oh, ask me this...' And (someone) will say, 'So why is it...?' But that works, too, because the students are on display. ...I am thinking (communicating to students) that you all need to ask me this question, it better be on your mind..." Because this press for student involvement is couched in an atmosphere that explicitly says, "I want you to succeed," students can be made uncomfortable and that discomfort becomes a motivation to respond.

As lead instructor, Dr. Nash prepares worksheets for recitations. By coordinating lectures with labs with recitations, he leverages his influence outside of the lecture room. He also uses the coordination and coherence of the course to press for increased and improved student involvement. Worksheets, for example, begin with easier questions and end with problems that are more difficult. Group work in class is encouraged and students are prompted to consult one another before the instructor provides information. They are also explicitly designed to be too long to be completed in recitation. Instructions on the sheet and stated by the graduate assistant suggest that the groups in recitation arrange to meet for coffee to continue their collaboration. This reinforces the non-competitive nature of the course and the value in putting ideas about chemistry into words and getting feedback from others.

Dr. Nash expressly states that his strategies are focused on developing analytical thinking skills. "...the more I can do to enhance the analytical skills of the students the better. Hopefully these students are gaining some chemistry knowledge here. But more so, hopefully what they are doing is they are learning problem solving skills...Whatever it takes, but we are going to get you through this."

This case study suggests the following points about reform-based teaching in a large class setting. By framing lecture content around problems based in student experience and posing and pressing direct questions to students, Dr. Nash provides modeling, practice, and feedback on cognitive skills critical to chemistry problem solving. He models how to pose questions and provides students with a variety of opportunities to pose their own questions to him and to each other in brief pair discussions during lecture. These strategies cannot be used frequently but they can be employed to make a point and are also leveraged by lecture coordinated with labs and recitations. His practices implement reform-based recommendations for pushing students to achieve, and making sure that students understand the value of these strategies for their own success.

Summary

The quantitative results provided limited information concerning the three major comparisons presented in Table 3. Our data only supported a contrast between mathematics and science instruction. Science faculty utilized strategies that emphasized connections to other disciplines and real-world situations while mathematics faculty more frequently applied small-group, collaborative arrangements. Observers whose field notes and follow-up interviews corroborated the quantitative findings also noted these strategies. Interviews support the conclusion that faculty engaged these practices with specific student outcomes in mind including motivation, retention, and depth of learning. What was not as clear in our observations was whether these instructors communicated to students how these strategies were intended to develop skills for better learning. In other words, were the students aware that these strategies were being taught to them as a means of processing information more effectively for long-term understanding and transfer to new situations? Minstrell (2001) describes a process of "assessing student understanding through further instruction." The process explicitly uses modeling, practice, and feedback to students on techniques for self-evaluation and productive thinking strategies. Our case study of Dr. Nash

suggested that he attended to this point but our qualitative data did not find that fellows communicated goals related to teaching learning strategies for their science or mathematics content.

Our in-depth look at Dr. Nash, suggested that a number of effective reform strategies could be incorporated in a lecture class format. He was explicit with students about the purpose and value of student interaction and its connection to effective learning. To communicate with a lecture hall full of students, one must be predisposed to making overt, explicit statements or actions and communicate his/her point. His strategies for soliciting and calling on students as well as actually "planting" questions, structure meaningful practice and provide modeling for the entire lecture hall. He also utilized his coordinating control over the recitations to provide additional practice and feedback on the kinds of learning skills he fosters.

Mathematics fellows invested time in devising problems that engaged small groups of students and solicited their ideas for problem solving while supporting multiple approaches to solutions. Science fellows likewise invested time in anticipating and designing connections between course content and other aspects of science or to the experiences of students. A next step is to build on both of these strategies by promoting more student reflection and self-evaluation of their own understandings of course content. This instructional and student behavior was rarely observed in this study.

Implications for Instructional Reform

The OTOP instrument proved difficult to quantitatively analyze, unlike the RTOP that provides a simple "score" (Swada et al., 2002). In contrast to the RTOP, it did provide a basis for broader comparison of instructional approaches and a basis for deeper discussion. Where this study used the OTOP as a basis for interviews that explored innovations in various types of class settings, departments could use the OTOP for collecting observations as a basis for faculty development and improvement. Rather than a score, the OTOP profile to look for what strategies work best in different situations (see Table 6). As with our interviews, these discussions can also be used to generate reflection and new ideas. For example, results from this study suggest that it would be fruitful for instructors to reflect on how to communicate to students the value of cultivating classrooms that improve learning. The OTOP itself or some version could be modified for student use in a course to give feedback to the instructor at key points during the course as a formative assessment and to stimulate discussion about improving the learning environment.

The data suggested that mathematics fellows were utilizing student-generated modes of investigation, alternative explanations, and strategies for challenging student ideas. These data motivate investigating the effects of using these strategies with greater frequency in both mathematics and science. Research shows questioning and development of classroom discourse is associated with better student learning. Van Zee (1997), for example, examined the impact of questioning strategies on student thinking in physics class. Her analysis demonstrated that skill in questioning based on knowledge of student thinking helped generate discourse that is more reflective and a more productive learning environment. Students were able to refine their ideas and make their ideas clearer. Students were able to consider the views of others more reflectively without jumping to premature closure on complex points. They also appeared to monitor the discussion and their own thinking in ways that led to a more productive synthesis of ideas as revealed in classroom discourse.

An implication for faculty professional development is that there are some faculty on any given campus that are actively trying new modes of teaching to improve effectiveness. The OTOP provides one method of classifying observations of these efforts but the expertise of faculty working on teaching should be utilized to a reflective application of OTOP to specific contexts. Rather than considering OTOP as a static instrument, use it to develop new or modified categories to meet the needs of particular learning environments. The new learning environments should generate new categories of observation that provide formative feedback to reform-minded faculty. Dr. Nash is but one example. The lecture hall is an important context for thinking about learning environments. Research in college physics instruction has already led to significant application of reform-based practices in larger lecture settings (see PER&D Group, 2008). Even if there are no resources for physically reconfiguring space as required by some innovations, departments can go a long way toward changing instructional norms by a concerted effort at communicating to students the learning goals embedded in new forms of teaching.

Finally, metacognitive teaching strategies, through which students are encouraged to check their own un-

derstanding, are an integral element of research on conceptual thinking. Strategies for metacognitive, conceptual, and divergent, thinking (Items 2, 6, & 7 respectively) were observed infrequently in this study. Metacognitive thinking skills are a significant factor in information recall and transfer (Bransford et al., 2000). These strategies hold promise for enhancing student-learning skills especially in highly structured material such as science and mathematics. In particular, mechanisms for "self-assessment [are] an important part of the metacognitive approach to instruction" (Bransford et al., p. 140) and have been shown to be effective in research on teaching (White & Frederickson, 1998). Having students write out their reasoning behind solutions to science and mathematics problems, or discuss, critique, and defend solutions in class, are ways of prompting students to trace their own thinking and learn from the thinking of others. This is a promising area for continuing research in collegiate teaching in science and mathematics.

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Appendix

Items of the Oregon Teacher Observation Protocol (O-TOP)

This lesson encouraged students to seek and value various modes of investigation or problem solving. *(Focus: Habits of Mind)*

Teacher encouraged students to be reflective about their learning. *(Focus: Metacognition – students' thinking about their own thinking)*

Interactions reflected collaborative working relationships and productive discourse among students and between teacher/instructor and students. *(Focus: Student discourse and collaboration)*

Intellectual rigor, constructive criticism, and the challenging of ideas were valued. *(Focus: Rigorously challenged ideas)*

The instructional strategies and activities probed students' existing knowledge and preconceptions. *(Focus: Student preconceptions and misconceptions)*

The lesson promoted strongly coherent conceptual understanding in the context of clear learning goals. *(Focus: Conceptual thinking)*

Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence. *(Focus: Divergent thinking)*

Appropriate connections were made between content and other curricular areas. *(Focus: Interdisciplinary connections)*

The teacher/instructor had a solid grasp of the subject matter content and how to teach it. *(Focus: Pedagogical content knowledge)*

The teacher/instructor used a variety of means to represent concepts. *(Focus: Multiple representations of concepts)*

Oregon Teacher Interview Protocol (O-TIP)

Student thinking:

How does your instruction support development of thinking skills?

1. [Habits of Mind] This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.

2. [Metacognition] Teacher encouraged students to be reflective about their learning

5. [Students preconceptions and misconceptions] The instructional strategies and activities probed students' existing knowledge and preconceptions.

7. [Divergent Thinking] Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.

Social skills & collaboration:

How does your instruction support development of social and collaborative skills?

3. [Students discourse and collaboration] Interactions reflected collaborative working relationships among students (e.g., students worked together, talked with each other about the lesson) and between teacher/instructor and students.

Content:

How does your instruction support development of content understanding?

4. [Rigorously challenged ideas] Intellectual rigor, constructive criticism, and the challenging of ideas were valued.

clear learning goals.

8. [Interdisciplinary connections] Appropriate connections were made to other areas of mathematics/science, to other disciplines, and/or to real-world contexts, social issues, and global concerns.

9. [Pedagogical Content Knowledge] The teacher/instructor had a solid grasp of the subject matter content and how to teach it.

Instruction:

Besides student thinking skills, content understanding, and social/collaborative skills, what else guides your selection of instructional approaches?

10. [Multiple representations of concepts] The teacher/instructor used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.

Turkish Prospective Chemistry Teachers' Alternative Conceptions about Acids and Bases

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The purpose of this study was to obtain prospective chemistry teachers' conceptions about acids and bases concepts. Thirty-eight prospective chemistry teachers were the participants. Data were collected by means of an open-ended questionnaire and semi-structured interviews. Analysis of data indicated that most prospective teachers did not have difficulties about macroscopic properties of acids and bases. However, despite chemistry instruction, most of the prospective teachers were found to have problems in understanding the neutralization concept, the distinction between strength and concentration of acids and linking the acids and bases topic to daily life. These findings have some implications for teacher education programs.

Several studies have been conducted in order to find out students' conceptions about different scientific concepts, e.g. particulate nature of matter (Abraham, Williamson, & Westbrook, 1994; Griffiths & Preston, 1992; Haidar & Abraham, 1991); electrochemistry (Garnett & Treagust, 1992; Sanger & Greenbowe, 1999); chemical equilibrium (Banerjee, 1995; Gussarsky, & Gorodetsky, 1990; Hackling & Garnett, 1985); and chemical bonding (Coll & Treagust, 2003; Peterson, Treagust, & Garnett, 1989).

One of the common findings of these studies is that students and even teachers have alternative conceptions. In addition, it was found that these alternative conceptions were quite resistant to change and continued to exist despite instruction. Moreover, students' alternative conceptions affect their achievement and learning negatively. As Head (1985) mentions, knowledge isn't scattered as separate units in our mind, rather it is found as complex cognitive structures and learning occurs by making links with the existing knowledge. If the new knowledge presented contradicts with the pre-existing knowledge, it is really hard to make sense of it. Therefore, when students are confronted with the new scientific knowledge; students having alternative conceptions interpret teachers' instruction and what they read in a textbook in the light of these alternative conceptions so that they cannot construct the scientific knowledge (Driver, Guesne, & Tiberghien, 1985; Driver, Squires, Rushworth, & Wood-Robinson, 1994; Gilbert, Osborne, & Fensham, 1982). Therefore, it is vital to consider these alternative conceptions while teaching

Like other chemistry topics, several research studies showed that students at different levels had alternative conceptions about acids and bases (Bradley & Mosimege, 1998; Cros et al, 1986; Cros, Chastrette, & Fayol, 1988; Demircioglu, Ayas, & Demircioglu, 2005; Hand & Treagust, 1988; Lin, Chiu, & Liang, 2004; Nakhleh, 1992; Nakhleh & Krajcik, 1994; Ross & Munby, 1991; Schmidt, 1991; Schmidt, 1995, 2000; Sheppard, 2006). It is known that one of the sources of students' alternative conceptions is the teacher's own alternative conceptions (Westbrook & Marek, 1992). Therefore, it is important to detect prospective chemistry teachers' alternative conceptions because they will teach chemistry in the future. Furthermore, such findings would be used to remedy these alternative conceptions in the teacher education programs. The purpose of this study is to investigate Turkish prospective chemistry teachers' conceptions about acids and bases:

i) macroscopic properties of acids and bases,

ii) neutralization concept and,

iii)distinction between strength and concentration of acids.

Therefore, the literature review will be discussed under three headings above that separate conceptions about acids and bases into specific parts.

Literature Review

Macroscopic properties of acids and bases

Research studies indicated that students had some alternative conceptions about macroscopic properties of acids and bases. For example, Hand and Treagust (1988) revealed that 16-year-old students thought acids as something which ate material away or which could burn you and bases as something which made up an acid. In addition, students indicated that testing for acids could only be made by trying to eat something away.

Furthermore, study of Nakhleh and Krajcik (1994), which investigated secondary school students' understanding of acid and bases, revealed some common alternative conceptions about macroscopic properties of

acids and bases. For example, some students thought that acids and bases had their own particular colour; bases were blue and acids were pink. Another alternative conception found in this study was that acids were strong and bases were not strong and harmful. Ross and Munby (1991) reported that also high school students had similar alternative conceptions about the macroscopic properties of acids and bases. According to Ross and Munby's study, high school students thought that acids tasted bitter and peppery and all acids were strong and poisonous. In terms of the properties of bases, they thought bases were blue and they considered all fruits as base.

In terms of the link between acids and bases with daily life, research of Cros et al. (1986, 1988) indicated that the concept of bases was less developed than that of acids among university science students. They could not link everyday life with bases. Therefore, these students could not give examples of bases from daily life easily.

Neutralization

As well as macroscopic properties of acids and bases, most students were found to have alternative conceptions about the neutralization concept. For example, Hand and Treagust (1988) stated that students described the neutralization as the breakdown of an acid or something changing from an acid. Schmidt (1991), who investigated high school students' conceptions about the neutralization concept, found that students thought neutralization reaction always resulted in a neutral solution. In addition, students thought that there were neither hydroxonium nor hydroxide ions in the resulting solution. Similarly, Schmidt (1995) found that senior high school students considered the products of neutralization reactions always had a pH of 7. Furthermore, Zoller (1990) indicated that college freshman chemistry students in Israel thought that salts formed as a result of neutralization reactions should always be neutral. In addition, Furio-Mas, Calatayud, Guisasola and Furio-Gomez (2005) stated that Spanish chemistry teachers interviewed in their study had the alternative conception that neutralization reactions always produced neutral products. This alternative conception was also common among student teachers in South Africa (Bradley & Mosimege, 1998).

Recently, Sheppard (2006) also stated similar findings that many high school students described neutralization as a simple mixing of acid and base and the product of neutralization as neutral. Similarly, Lin et al. (2004) reported that 9th grade students lacked conceptual understanding about neutralization reactions. For example, when students were asked about reactions between a strong acid and weak base, they gave explanations based on a memorized rule which states that "adding strong acids into weak bases will produce acidic solutions" without understanding the underlying reason for this rule (p. 6). In a similar vein, students thought that reaction between weak acids and weak bases will produce neutral solutions.

Furthermore, Demircioglu et al. (2005) designed a teaching method in order to promote conceptual change among year 10 students in the context of acids and bases. As a result of this study, they reported that alternative conceptions about acids and basis particularly about neutralization concept could not be eliminated among year 10 students despite conceptual change instruction. For example, after conceptual change instruction, some students in the experimental group still had the alternative conceptions that "At the end of all neutralization reactions, there is neither H+ nor OH- ions in the resulting solutions." and "All salts are neutral." (p. 46).

Concentration and strength

Like the neutralization concept, students had alternative conceptions about the distinction of concentration and strength. Sheppard (2006) found that high school students had a belief that an increase in the concentration of acids would lead an increase in their strengths. In addition, Ross and Munby (1991) stated that high school students related the acid strength with the number of hydrogen atoms within the formula; the more number of hydrogen atoms within the molecule of an acid, the more strength that acid has. Similar finding was reported by the study of Lin et al (2004) stressing that 9th grade Taiwanese students considered the number of hydrogen atoms in a chemical formula as a measure of the strength of acids.

The above research findings indicated that students at different levels had alternative conceptions about acids and bases concepts. The present study aims to find out Turkish prospective chemistry teachers' conceptions about acids and bases, specifically macroscopic properties of acids and bases, neutralization concept and distinction between strength and concentration of acids. Research question of this study is as follows:

What are the Turkish prospective chemistry teachers' conceptions about

a) macroscopic properties of acids and bases?

b) neutralization concept?

c) distinction between strength and concentration of acids?

Method

Sample

38 prospective chemistry teachers enrolled in the Department of Secondary Science and Mathematics Education participated in this study. Students enrolled in the Secondary Science and Mathematics Education Department follow a five-year program where they complete subject-matter courses in the first seven semesters. In the context of chemistry education program, subject matter courses involve general and advanced chemistry courses, such as General Chemistry I, General Chemistry II, Analytical Chemistry, Physical Chemistry, Organic Chemistry and Inorganic Chemistry. After completing subject matter courses, they begin to take pedagogical courses in the last three semesters such as Methods of Science Teaching, Instructional Planning and Evaluation, Development and Learning, Instructional Technology and Material Development etc. In addition, they take three school placements where they have the chance to observe their cooperating teachers and teach chemistry in high schools. Upon graduation, they gain qualified teacher status and can be employed by Ministry of Education as chemistry teachers in high schools. Most of the prospective teachers in this sample were at the 4th year of their program though there were some 3rd and 5th year prospective teachers in the study. However, most of them completed most of the subject matter courses at the time of the study.

Instruments

A questionnaire with five open-ended questions and semi-structured interviews were used to collect data. Questions in the questionnaire were prepared by the author based on the students' alternative conceptions in the literature. However, question 2 was adapted from the study of Schmidt (2000). In order to achieve the content validity, two chemistry educators examined the appropriateness of items in the questionnaire. For the reliability of the questionnaire, firstly, the researcher carried out data analysis by forming categories according to the prospective teachers' written responses. Then, she explained the categories and their descriptions to a chemistry educator and wanted her to match prospective teachers' written responses under these categories. The categories put by the colleague were compared with the categories of the researcher. There was a close match between categories indicating that the questionnaire was reliable.

Questions in the questionnaire

Question 1

The purpose of the question 1 was to obtain prospective teachers' conceptions about macroscopic properties of acids and bases. Prospective teachers were asked to identify the given properties of acids and bases as either true or false.

Properties of Acids and Bases	True	False
a. All acids are corrosive		
b. Acids taste bitter		
c. Bases taste sour		
d. Fruits are always basic		
e. All salts are neutral		
f. Acids are slippery		
g. Acids turn red litmus paper into blue		
h. Bases turn blue litmus paper into red		

Questions 2, 3 and 5 were asked to elicit prospective teachers' views about the neutralization concept.

Question 2

An aqueous solution of 1 mole of NaOH (sodium hydroxide) was added to an aqueous solution of 1 mole of CH_3COOH (acetic acid) in equal volume. What would you say about the quantity of the $[H_30^+]$ and $[OH^-]$ ions in the resulting solution? Please explain your answer.

Question 3

Please give daily life examples of neutralization reactions.

Question 5

An aqueous solution of 1 mole HCOOH (formic acid) was added to an aqueous solution of 1 mole of NH_3 (ammonia) in equal volume. What would you say about the quantity of the $[H_30^+]$ and $[OH^-]$ ions in the resulting solution? Please explain your answer.

Question 4 was about the distinction between concentration and strength of an acid.

Question 4

Which acids below is the strongest one? Please explain with your reasons.

a. 0.5 M HCl
b. 0.05 M HCl
c. 0.0001 M HCl

For triangulation, semi-structured interview questions were constructed according to the analysis of written responses to the questionnaire and interviews were carried out with seven prospective teachers. Elapsed time between questionnaire and interviews was about two weeks. The researcher interviewed prospective teachers individually. Interviews lasted approximately 25 minutes and all the interviews were audio-taped. The main purpose of the interviews was to obtain deeper information about prospective teachers' reasoning and understand the reasons for their answers in the questionnaire. In order to select interviewees, prospective teachers' written responses were analyzed by constructing categories. Responses belonging to different categories in the questionnaire were investigated in depth during the interviews.

Interview questions were prepared in advance based on the prospective teachers' written responses and alternative conceptions about acids and bases in the literature. For example, in the questionnaire, for the first question, prospective teachers only identified the given properties of acids and bases as either true or false without mentioning their reasoning. During the interview, they were asked to explain reasons for their choice. To clarify, if the prospective teacher identified the statement "All salts are neutral" as true in the questionnaire; she/he was asked "Why do you think all salts are neutral" during the interview. Similarly, in the questionnaire, prospective teachers were asked about neutralization reactions, distinction between strength and concentration of an acid and the daily life application of the neutralization reactions. In order to explore prospective teachers' conceptions in depth and understand their reasoning, during the interview, questions such as "How does acid rain form?"; "Why would the hydroxyl ion concentration be greater than the hydroxonium ion concentration in the reaction of sodium hydroxide and acetic acid?"; "Which one is stronger? H_2SO_4 or H_3PO_4?"; "What do you understand from the strength of acid?" etc.

Analysis of Written Data

Prospective teachers' written responses were analyzed by constructing five broad main categories;

i) *correct answers* category,
ii) *correct answer-incorrect explanation* category,
iii) *correct answer -no explanation* category and
iv) *incorrect answers* category.
v) *no-responses category*

For example, for the 2nd question, an explanation about the concentration of $[OH^-]$ and $[H_3O^+]$ ions in the reaction of sodium hydroxide and acetic acid was asked. In addition, prospective teachers were required to explain their answers.

Correct answers category involved responses indicating both correct answer to the question and correct explanation. For example, "hydroxyl ion concentration would be more." is the correct answer. Explanation of this referring to the hydrolysis would be the correct explanation.

Correct answer- incorrect explanation category included the responses indicating that "hydroxyl ions would be more", however, giving incorrect explanations such as, "There is excess of base since sodium hydroxide completely ionizes whereas acetic acid does not completely ionize."

Correct answer- no explanation category involved the response "hydroxyl ions would be more" without giving any explanations.

Incorrect explanations category involved incorrect answer "hydroxonium ions would be more" or "both hydroxonium and hydroxyl ions would be equal"

No-responses category included empty answers. Table I below indicates the analysis of prospective chemistry teachers' written responses.

Results

Macroscopic properties of acids and bases

Questions 1 a, 1 b, 1 c, 1 d, 1 f, 1 g, 1 h were about macroscopic properties of acids and bases. As seen from Table I, analysis of written responses indicated that most prospective teachers were aware of the macroscopic properties of acids and bases. However, some prospective teachers (11 and 13 student teachers) thought that acids tasted bitter and taste of bases was sour respectively. Most of the prospective teachers stating that acids taste sour and bases taste bitter came to such reasoning by thinking of specific examples of acids and bases from daily life:

R[1]: Why do you think that acids taste sour and bases taste bitter?

Table I
Prospective Teachers' Written Responses for Questions

Questions	Number of Prospective Teachers A*	B*	C*	D*	E*
Question 1					
a. All acids are corrosive	32			6	
b. Acids taste bitter	27			11	
c. Bases taste sour	25			13	
d. Fruits are always basic	38			0	
e. All salts are neutral	28			10	
f. Acids are slippery	37			1	
g. Acids turn red litmus paper into blue	37			1	
h. Bases turn blue litmus paper into red	37			1	
Question 2 An aqueous solution of 1 mole of NaOH (sodium hydroxide) was added to an aqueous solution of 1 mole of CH3COOH (acetic acid) in equal volume. What would you say about the quantity of the [H30+] and [OH-] ions in the resulting solution? Please explain your answer.	8	15	5	10	
Question 3 Please give daily life examples of neutralization reactions.	4				34
Question 4 Which acids below is the strongest one? Please explain with your reasons. a. 0.5 M HCl b. 0.05 M HCl c. 0.0001 M HCl	6			32	
Question 5 An aqueous solution of 1 mole HCOOH (formic acid) was added to an aqueous solution of 1 mole of NH3 (ammonia) in equal volume. What would you say about the quantity of the [H30+] and [OH-] ions in the resulting solution? Please explain your answer.	5		7	22	4

* A refers to correct answer, correct explanation, B: correct answer, incorrect explanations, C: correct answer, no explanation, D: incorrect answer, E: no-responses

S: For example, there is acid in lemon and it tastes sour. Also, I know that soap is a base and I think that it does not taste sour. So bases do not taste sour.

However, some student teachers thought the opposite by claiming that acids taste bitter and bases taste sour depending on their prior knowledge:

"I am not sure but, there is some information about these in the high school chemistry textbooks. I think that acids taste bitter and bases taste sour."

This prospective teacher did not depend on examples of acids and bases from daily life while explaining the taste of acids and bases; instead her previous knowledge in high school influenced her decision.

Neutralization

Questions 1e, 2, 3 and 5 were asked in order to find out prospective teachers' conceptions about the neutralization concept. Analysis of written responses for question 1e showed that while the great majority of prospective teachers (28 of them) did not classify all salts as neutral, ten of them mentioned that all salts were neutral (Table I). In the interview, one of the student teachers asserted the neutrality of salts due to the neutralization reactions:

"Since salts were formed at the end of neutralization reactions. They are neutral, neither acidic nor basic."

This student teacher had the idea that neutralization reaction caused neutral products, salts. The alternative conception that neutralization reactions yielded a neu-

tral product has also been reported in several research studies (Schmidt, 1991, 1995; Sheppard, 2006).

Interviews with prospective teachers indicated that some prospective teachers (3 out of 7) only considered the reaction of strong acids and strong bases as neutralization reactions. When asked to name the reaction between CH_3COOH and NaOH, a prospective teacher gave the following explanations:

R: What is this reaction?

S: It is an acid base reaction.

R: Can we call it a neutralization reaction?

S: It is not a neutralization reaction. For the neutralization reaction to occur, strong acid and strong base should react. There should not remain anything, but here remains some base in this reaction.

The above transcript shows that prospective teachers have difficulties in understanding the meaning of the neutralization concept.

As seen from Table I, for the 2nd question, written responses from 38 prospective teachers revealed that though most of the prospective teachers replied that the concentration of $[OH^-]$ would be more than $[H_3O^+]$ ions in the solution when strong base and weak acid react, only eight prospective teachers could give correct explanations. On the other hand, 15 prospective teachers gave incorrect explanations despite they could say that hydroxyl ion would be more. They considered there would be excess of base due to the strength of the base. One of the prospective teachers having this view gave the following explanations during the interview:

R: Why would the hydroxyl ion concentration be more than the hydroxonium ions?

S: Sodium hydroxide is a strong base and would ionize completely. Therefore, there would be 1 mol hydroxide ions. However, since acetic acid is a weak base and would not ionize completely, there would be less than 1 mol hydroxonium ion. There would be excess of base, in other words, hydroxide ions would be more.

Another prospective teacher wrote in the questionnaire:

"$NaOH+CH_3COOH \rightarrow CH_3COONa + H_2O$, in this acid base reaction, sodium acetate, the salt, and the water forms. Since CH_3COOH is a weak acid and NaOH is a strong base, there would be more hydroxide ions."

Another written response was "There would be more $[OH^-]$ than the $[H_3O^+]$ because NaOH is a strong base and it will dissociate into its ions completely. Since the acetic acid does not completely dissociate into its ions, there will be less $[H_3O^+]$"

The above explanations show that most prospective teachers had rather superficial knowledge about the neutralization reactions.

On the other hand, ten prospective teachers gave incorrect response to this question. Incorrect responses for the 2nd question, related to the neutralization reaction of CH_3COOH and NaOH, were categorized under two sub-categories:

a) Quantity of $[H_3O^+]$ = Quantity of $[OH^-]$

b) Quantity of $[H_3O^+]$ > Quantity of $[OH^-]$

Nine prospective teachers thought that quantity of hydroxonium and hydroxyl ions were equal to each other. Two main aspects of thinking dominated this answer. Two prospective teachers explained the equality of these ions due to the neutralization reactions: For example, one of them wrote in the questionnaire: "$NaOH+CH_3COOH \rightarrow CH_3COONa + H_2O$, since this is a neutralization reaction, the concentration of $[OH^-]$ would the same as $[H_3O^+]$ ions." Another prospective teacher gave the following explanations during the interview:

R: Why did you say that the concentration of hydroxonium and hydroxyl ions were equal?

S: This is the neutralization reaction and the environment should be neutral and the pH value should be 7, therefore hydroxonium and hydroxyl ions are equal.

However, seven prospective teachers considered the formation of water. The written response given by one of them was "$NaOH+CH_3COOH \rightarrow CH_3COONa + H_2O$. In this reaction, there are 1 mol NaOH, 1 mol CH_3COOH and therefore the water should be one mol and since 1 mol water contains 1 mol H_3O^+ and OH^- ion, the concentration of these ions should be equal to each other." Interviews with participants reflected similar responses given in the questionnaire. For example, both in the questionnaire and interview, one participant's explanations were: "In the reaction of $NaOH+CH_3COOH \rightarrow CH_3COONa + H_2O$, 1 mol H_3O^+ comes from the CH_3COOH and 1 mol OH^- comes from the NaOH and these form the water molecule."

On the other hand, only one prospective teacher wrote that the quantity of hydroxonium ions was more than the hydroxyl ions by giving the following explanations both in the questionnaire and interview:

"In the acetic acid, there are 4 protons and there is only proton in the sodium hydroxide. Then, three protons from acetic acid will remain making the quantity of $[H_3O^+]$ more."

Similarly, for the 5th question, when asked about the

quantity of [OH^-] [H_3O^+] ions at the resulting reaction of a weak acid and weak base, written responses revealed that only five participants explained it correctly. Though seven student teachers wrote the correct answer, they did not give any explanations at all. On the other, majority of the prospective teachers (22 out of 38) could not give correct explanations (Table I). Incorrect responses are categorized in two different ways:

a) Quantity of [H_3O^+] = Quantity of [OH^-]

b) Quantity of [OH^-]> Quantity of [H_3O^+]

However, written responses revealed that the majority of prospective teachers (14 participants) referred to equal concentrations of hydroxonium and hydroxyl ions. Eleven of them had this thought due to the reaction between weak base and weak acid. An example for these written responses was: "Both the base and the acid are weak. Therefore, the concentration of hydroxonium and hydroxyl ions are equal." Another written response was "Both of them are weak and they neutralize each other due to this." During the interview, one of them also gave similar explanations:

"There is weak acid and weak base in this reaction. Therefore, they neutralize each other. The pH should be seven and hydroxonium and hydroxyl ions are equal to each other."

According to the written responses, three prospective teachers explained the equality of hydroxonium and hydroxyl ions due to the formation of water. Their written responses and the interviews with them revealed the above reasoning:

"...1 mol OH comes from NH_3, 1 mol H comes from formic acid and they make up water therefore they need to be equal."

Seven prospective teachers wrote that the quantity of [OH^-] is more than [H_3O^+] based on their thought of NH_3 as a strong base: "....NH_3 is a strong base and HCOOH is a weak acid. Therefore, the quantity of hydroxyl ion is more..."

On the other hand, one prospective teacher wrote that the quantity of [OH^-] was greater than [H_30^+] ion by finding out the number of hydrogen atoms in both formic acid and ammonia. She gave similar explanations during the interview:

R: Why do you think that hydroxyl ion is greater than hydroxonium ion?

S: The acid, formic acid has 2 protons and ammonia has three protons. For the neutralization to occur, two proton acid and two proton base are needed. Therefore, one proton remains from ammonia and quantity of [OH] is greater.

As well as the neutralization concept, this study also indicated prospective teachers had difficulties in linking the acid and base topic to daily life. Analysis of written responses given to question 3 revealed that only four prospective teachers could give examples for the neutralization process from daily life (Table I). Three of them mentioned the neutralization of acid in the stomach by anti-acid tablets in the questionnaire. One of the student teacher's written response was "When our stomach burns, it means that there is an excess of acid, in order to neutralize it, we need anti-acid tablets because base of the anti-acid neutralizes the acid of the stomach. Consequently, the person gets comfortable." On the other hand, only one prospective teacher wrote the neutralization of bee sting with the alkalis: "When the bee stings, a basic substance should be applied in order to reduce the pain by means of neutralization since bee stings are acidic."

On the other hand, the great majority of prospective teachers (34 of them) did not respond correctly to this question at all. In the interview, when they were asked to link the neutralization process with daily life, most of them could not give any explanations. Some prospective teachers said that neutralization reactions perhaps have to do with cleaning agents used in the house. However, they could not explain how.

Moreover, in order to assess whether or not prospective teachers could link the acid and base topic with daily life, prospective teachers were asked to describe how acid rain formed in the interviews. Though they heard about the acid rain and had some thoughts, none of them could explain the formation of it:

R: Have you ever heard about acid rain, what is it? How does it occur?

S: When the quantity of a gas, but I don't know which gas, increases, acid rain forms.

R: Do you know how it forms?

S: I do not know.

Another prospective teacher gave the following explanations:

"Due to the air pollution, acid rain occurs, but I only know this."

These statements of prospective teachers show the loose link between acid and base topic to daily life applications.

Concentration and Strength

Written responses for Question 4 showed that the majority of prospective teachers (32 of them) were confused about the distinction of concentration and strength of an acid. Only six prospective teachers said

that the acids had the same strength (Table I). For example, one of the prospective teacher's explanations in the questionnaire was as follows: "In case of acid strength, we need to look at how much the acid dissociates. Acid strength and acid concentration are two different concepts. In this question, the acid is the same, HCl, so they have the same acid strength despite differences in the acid concentration."

The above is an example of a correct response with correct explanations. However, 32 student teachers could not answer this question correctly. Analysis of written responses revealed that most prospective teachers (21 of 32 participants) related the acid strength with hydrogen ion concentration. For example: "The strongest acid is 0.5 M HCl because in 0.5 M HCl, there is the most hydrogen ion concentration, making it the strongest." Another four participants wrote that the acid strength would increase with the increase in acid concentration making 0.5 M HCl the strongest. Seven participants found the pH of each acid given and concluded that 0.5 HCl was the strongest. For example: "pH= -log [H^+], for 0.5 M HCl, pH= -log [0.5]= 1log 5. For 0.05 M HCl, pH= 2log 5 and for 0.0001 M HCl, pH= 4. Therefore, the lowest pH means the strongest acid. In this question, it is 0.5 M HCl."

Interview results also showed consistencies with the written responses. During the interview, two prospective teachers explained the strength of the acid with respect to the concentration of the acid:

I: You wrote that 0.5 M HCl is the strongest of the others. Why?

S: I thought 1 liter for all of them, then in 1 liter there is 0.5 mol HCl, which is the most compared to the others. Therefore, I said 0.5 M HCl is the strongest.

I: What do you understand from the strength of acid?

S: The more concentrated the acid, the most strength the acid has.

These prospective teachers were not aware of the distinction of the concentration and strength of acids.

On the other hand, most prospective teachers (four prospective teachers) explained the strength of acids with relation to the hydrogen ion concentration in the solution when asked to describe what the strength of an acid meant. One of them gave the following explanations:

R: What does strength of an acid mean?

S: It depends on the hydrogen ion concentration.

R: In this question, how did you decide that 0.5 M HCl is the strongest?

S: I looked at the pH value, in a way, hydrogen ion concentration. In 0.5 M, there is more hydrogen ion concentration and the pH value was the smallest for that one.

On the other hand, one prospective teacher who wrote in the questionnaire that acid strength was dependent on the concentration of the acid changed her mind during the interview when asked to explain the meaning of the strength of acids:

"Acid strength depends on the degree of ionization.... In fact, these acids have the same strength because they are the same acid. Only their concentrations are different."

In addition, some prospective teachers said that strength of acids increased with the number of hydrogen atoms in the formula:

R: Which one is stronger? H_2SO_4 or H_3PO_4?

S: H_3PO_4

R: Why? Can you explain?

S: Because it has more hydrogen, therefore gives more hydrogen ions.

One of the prospective teachers who explained the strength of acids in terms of concentration gave another definition when asked to compare the strength of 0.0001 M HCl and 1 M CH_3COOH in the interview:

"HCl is stronger. Acid strength is related to how much an acid can ionize in water. HCl can ionize 100%, therefore it is strong."

This shows the incoherency of alternative conceptions. Students can give different explanations for similar phenomena. Inconsistency of alternative conceptions is supported by several research findings (Bar & Galili, 1994; Driver & Oldham, 1986).

Conclusions and Implications

The purpose of this study was to understand prospective chemistry teachers' conceptions about acid and bases, specifically macroscopic properties of acids and bases, neutralization reactions and distinction between concentration and strength of acids. Written responses revealed that most prospective teachers did not have alternative conceptions about the macroscopic properties of acids and bases. However, some prospective teachers mentioned acids having bitter and bases sour taste. This alternative conception was also reported by the study of Ross and Munby (1991).

The present study also indicated that the neutralization concept was one of the concepts about which prospective teachers had alternative conceptions. Both written responses and interview results showed that some prospective teachers had problems in understand-

ing what neutralization reaction meant. They considered that neutralization reaction always caused a neutral solution, thereby salts were considered as neutral. In addition, some prospective teachers did not consider the reactions between weak acid and strong base as neutralization reactions. This is a common alternative conception also found among high school students in several research findings (Demircioglu et al., 2005; Schmidt, 1991, 1995; Schmidt, 2000; Sheppard, 2006). This alternative conception may result from the daily life language since neutral means having neither side in the everyday language. This may cause prospective teachers think that the product of neutralization reactions should always be neutral; neither acidic nor basic. Therefore, I suggest that emphasizing the distinction between the use of this word in daily life and chemistry may help to prevent this alternative conception.

As well as the meaning of the neutralization concept, most prospective teachers could not explain the principle behind the neutralization reaction between a strong base and weak acid correctly. For example, most of them mentioned the excess of hydroxyl ions since the base is stronger in the neutralization of strong base and weak acid. This type of reasoning is also encountered among high school students (Sheppard, 2006). For the reaction between strong base and weak acid, some prospective teachers in this study mentioned the equality of hydroxonium and hydroxyl ions due to the formation of water. The study of Schmidt (2000) also confirmed this finding in his study.

In addition, most prospective teachers in this study thought that a weak acid and weak base would cancel each other and produce a neutral product. This indicates the superficial knowledge prospective teachers have about the neutralization concept without conceptual understanding. Lin et al (2004) reported the similar finding by explaining that 9th grade students in their study thought that a weak acid and weak base would produce a neutral product. They claimed that students developed this type of reasoning due to memorization.

Another problematic issue in this topic was that most prospective teachers could not make the distinction between strength and concentration of acids. They thought that the concentrated acid would be the strongest acid. Most of them came to this conclusion by finding out the hydrogen concentration in the solution and pH value in order to evaluate the strength of acids. The alternative conception that pH was a measure of strength of acid was found among high school students in the research of Sheppard (2006). In addition, it was found that some prospective teachers thought the increase in the number of hydrogen atoms in the molecular formula of acids caused an increase in their strength. Similar thoughts such as relating the strength of acids with the number of hydrogen atoms within their molecular formula was also reported in the literature (Lin et al., 2004; Ross & Munby, 1991). In addition, Bradley and Mosimege (1998) reported that student teachers in South Africa could not arrange some common substances in terms of their acid strength.

Another finding of this study was that most of the prospective teachers could not link the neutralization concept with daily life. Similarly, none of the prospective teachers could explain how acid rain formed. This indicates the difficulty of prospective teachers in linking acids and bases with daily life. Therefore, prospective teachers should be encouraged to link acids and bases with daily life in teacher education program.

Though studies of Cros et al. (1986, 1988) indicated the difficulties of university science students in giving daily life examples of bases, cited research studies have not reported the difficulties of students in linking the neutralization process with daily life.

Most of the time, interviews with participants were consistent with written responses in the questionnaire. However, in one situation, one of the student teachers changed her mind and gave correct explanations during the interview. This may be mainly because of the prospective teacher paid more attention and thought more when giving explanations to the questions during the interview.

In sum, it could be said that prospective teachers in this study were found to have similar alternative conceptions as described in the literature. This provides an evidence of the *stability* of alternative conceptions despite *advanced chemistry instruction*. Considering the fact that these prospective teachers would teach chemistry in the future, it is important to eliminate these alternative conceptions in the teacher education programs. Therefore, this study has some implications. Firstly, chemistry instruction in teacher education programs, which fosters conceptual understanding rather than rote memorization, may help to eliminate student teachers' alternative conceptions. For this purpose, an efficient learning environment where prospective teachers have the opportunity to discuss their ideas and reflect on their thinking may be helpful. Discussion with peers can provide the opportunity for prospective teachers to build on each other's ideas and take their

thinking forward (Driver et al., 1994). For example, discussions with prospective teachers about what is meant by a neutralization reaction and the meaning of concentration and strength of acids may help prospective teachers understand the neutralization concept and the distinction between concentration and strength of acids and bases. In addition, the emphasis of acid and bases topic with the daily life may prevent rote memorization and provide the link of the scientific knowledge with daily life.

This study has made a contribution to the chemistry education research. First of all, most of the studies explored high school students' conceptions about acids and bases and there are few studies conducted in order to explore prospective teachers' conceptions about acids and bases (Bradley & Mosimege, 1998). Similarly, few studies have focused on finding out prospective teachers' ability to link daily life with an acid and bases topic (Cros et al., 1986, 1988). They reported the difficulties of prospective teachers in giving daily life examples of bases. This study also reported the difficulties of prospective teachers in linking the neutralization concept with daily life.

Limitations of the Study

This study has some limitations. Firstly, in this study, data were collected from 38 prospective chemistry teachers enrolled in a university in Turkey. This is one of the limitations and as a future study; I would suggest conducting the same study with the sample of prospective teachers from different universities in Turkey. Moreover, in-service chemistry teachers' conceptions about acids and bases concepts could be examined in future studies.

Similarly, prospective teachers' conceptions about many other aspects of acids and bases were not investigated in this study. Instead prospective teachers' conceptions about macroscopic properties of acids, bases, neutralization concept and distinction between concentration and strength of acids were explored. However, for the future study, prospective chemistry teachers' conceptions about other aspects of acids and bases topic, e.g. titration, acid base models etc. could be investigated. Moreover, reasons lying behind the alternative conceptions could be explored as a future study.

As another limitation, this study only revealed prospective teachers' alternative conceptions about acids and bases but did not focus on how to eliminate these alternative conceptions despite some recommendations made. Therefore, as future study, it would be beneficial to evaluate the effectiveness of teaching strategies such as case-based instruction, cooperative learning strategies, concept mapping or any other strategies designed for the elimination of alternative conceptions in teacher education programs.

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Crossing the Barriers Between Preservice and Inservice Mathematics Teacher Education: An Evaluation of the Grant School Professional Development Program

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A 2-year school-based mathematics professional development program is described and evaluated after its first year of implementation. Included in this program as its first course was a unique methods course in elementary education involving both preservice students and inservice teachers who cooperatively studied and applied reform pedagogy. The program resulted from the collaborative efforts of two institutions of higher education, a neighboring school district, the principal and teachers of one school within that district, and the state office of education. Evaluation of the first year of the program consisted of assessing the beliefs and perceptions of both preservice students and inservice teachers, along with an assessment of the mathematical achievement of the children within the classes of those teachers. Pre- and post-assessments of the preservice students and inservice teachers' beliefs regarding reform pedagogy were administered using the IMAP [Integrating Mathematics and Pedagogy] Web-Based Beliefs Survey (2006). Likert scale surveys were used to assess perceptions regarding course climate and participant relationships from both teacher groups. The mathematical achievement of children was assessed in three ways: The Wide Range Achievement Test-3 (Stone, Jastak, & Wilkinson, 1995), the Utah state criterion-referenced assessment, and performance assessments developed specifically for use at the school. Data obtained from all sources indicated positive effects upon teachers and children, thus providing substantial evidence in support of both the value of the methods course itself and the overall professional development program. An additional evaluation will be conducted following the second year of the program.

Theoretical Framework

Since the publication of the *Curriculum and Evaluation Standards for School Mathematics* (National Council of Teachers of Mathematics [NCTM], 1989) pioneering educators have promoted unprecedented levels of mathematical thoughtfulness among students of all ages and across wide populations. *Principles and Standards for School Mathematics* (NCTM, 2000) has continued to encourage important changes in mathematics education. Despite these efforts, however, international comparisons of mathematical competency often leave American students wanting (National Center for Education Statistics, n.d.), and data indicate that a majority of American adults fear mathematics (Burns, 1998). According to Burns, "Even in the face of widespread failure in learning mathematics, we seem to want to cling to educational methods with a nostalgia for them that has long outlasted their usefulness and has perpetuated failure" (1998, p. x). She continued, "The way we've traditionally been taught mathematics has created a recurring cycle of math phobia, generation to generation, that has been difficult to break" (p. x).

Ma (1999) postulated that teacher preparation might be the force needed to foster legitimate reform. This emphasis on the role of preservice teacher preparation is in some ways quite ironic. Preservice teacher preparation is viewed as the vehicle for improving inservice teacher performance. Yet, there is overwhelming evidence from multiple content areas (e.g., Bahr, 2003), that preservice preparation is significantly enhanced by strong and consistent preservice/inservice teacher part-

nerships that involve interactions with children (e.g., Bahr, 2007; Kagan, 1992; Richardson, 1996). That is to say, an effective method for teacher educators to use in promoting reform-based inservice teaching of mathematics is to enlist the support of inservice teachers in providing field practicum sites for preservice students to explore, investigate, and make sense of reform-based mathematics methodology.

Additional support for partnering with elementary schools comes from the literature surrounding the notion of Professional Development Schools, a term appearing 2 decades ago in the Carnegie Forum on Education and the Economy's *A Nation Prepared: Teachers for the 21st Century* (1986) and the Holmes Group's *Tomorrow's Teachers: Report of the Holmes Group* (1986). Goodlad (1994) further encouraged partnering when he created the term "Partner Schools" to describe the kind of synchrony between university schools of education and public schools that would significantly encourage reform in teacher education. This "individual and institutional renewal" (p. 17) would occur because both types of institutions have "overlapping self-interests" (p. 124). Such partnering, according to Sumara and Luce-Kapler (1996), would tighten the loose connection between the university and school experience and help preservice teachers to negotiate the conflict between the identities they develop during course work and the separate identities they develop during field practica. Feiman-Nemser (2001) suggests that carefully structured field assignments within partnering relationships help to situate theoretical learning in practice and promote reflection.

Field practica that occur within inservice classrooms are not without their own unique set of challenges, however. One such challenge occurs when there is a mismatch between the reform pedagogy espoused in methods courses and the more traditional pedagogy that often characterizes public school classrooms (Ball, 2001). In our experience, the following observation by Herrera and Owens (2001) remains descriptive even today:

> While state curriculum frameworks and textbook publications show decided change directly connected to the reform movement, at the classroom level only minimal change has taken place in important areas that affect students—how mathematics is conceptualized and how it is taught. (p. 91)

Our observation is not intended to demean inservice teachers. Years of professional development work in the field have left us with admiration for the sacrifice and diligence they exhibit on a daily basis. Nevertheless, research has consistently demonstrated that, when there is incongruence between the teaching that occurs in the inservice classroom and the methods espoused by the university teacher educator, those methods are often marginalized (Eisenhart, Borko, Underhill, Brown, Jones, & Agard, 1993; Hollingsworth, 1989; Tabachnick, Popkewitz, & Zeichner, 1979-1980). On the other hand, a seamless integration of course and clinical work founded upon "pedagogies that link theory and practice" (Darling-Hammond, 2006, p. 300) leads to strong, effective teacher preparation.

We wanted our students to experience the benefits of working with children in real classrooms, and we wanted them to do so where reform pedagogy was valued and applied. In order to encourage and support reform pedagogy in existing classrooms, we were working on projects to engage inservice teachers in our service area in professional development. We wondered: To meet these goals, why not work with preservice students and inservice teachers simultaneously?

Design of the Study

In the spring of 2003, a partnership was formed between the Utah State Office of Education, a Utah school district, the entire faculty and administration of a school within that district (Grant Elementary School), and two Utah institutions of higher education. The initial conversations of this partnership were geared toward delivering a once-a-week preservice elementary mathematics methods course at Grant School to which the inservice teachers would be invited to attend. The school and district administrations agreed to finance released time for the teachers to engage in the course. Two or three preservice students would team with each inservice teacher for the semester. During the weekly on-site methods class, each team would spend 2 hours in methods instruction and 1 hour in the inservice teacher's classroom. The inservice teacher would guide the preservice students in planning reform-based lessons as part of the methods instruction. Then the team would implement that plan in the inservice teacher's classroom, with the preservice students assuming increasing responsibility for lesson implementation over the duration of the semester.

About the same time the above partnership discussions were occurring, similar conversations were being held with the Grant School faculty to iron out the details associated with implementing the program. One issue that surfaced was that of providing incentives for

inservice teacher participation. After discussion, the idea was proposed to provide additional coursework to enable teachers to earn the recently developed Utah State Office of Education (USOE) Elementary Mathematics Endorsement (USOE, 2007) and perhaps even a master's degree. Through the collaboration of the various parties involved, a plan was worked out that would enable Grant inservice teachers to achieve the endorsement as part of a 2-year master's degree program with a sponsoring institution of higher education. This program would begin with the preservice-inservice methods course of three credit hours, continue with an additional 15 hours of mathematics content and pedagogy functioning as elective graduate credit, and include 21 credit hours of required master's courses taken during summers. Specifically, the 18 hours of endorsement credit include 2 hours in pedagogy, 2 in assessment, 2 relative to the state curriculum, 2 in developmental issues related to mathematics, 2 in technology, and 8 hours devoted to mathematics content.

After the first course, the Grant inservice teachers were presented the option of continuing their coursework during the school day but actually voted to meet after school instead. This desire was a reflection of the uneasiness they felt in missing instructional time with their students during attendance in the first course.

This school-university partnership facilitated the creation of an ongoing, sustained, schoolwide professional development system in mathematics education. Shortly after its inception, word spread throughout the district regarding its existence, and a large number of teachers asked to be involved. Their requests were partially accommodated by: (a) allowing 10 additional teachers from four other elementary schools in the district to join with the Grant teachers, making a total of 21 participants; (b) creating another cohort, commencing in the winter semester, comprising 23 teachers from 12 other district schools; and (c) planning to launch a similar partnership system at another district school if the Grant School Professional Development Program (Grant Program) proved beneficial, which did eventuate. (See Conclusion.)

Goals of the Program

As the project unfolded, three fundamental goals became the focus of the Grant Program:

- Increased mathematics achievement for students at Grant Elementary School.
- Implementation of reform-based mathematics pedagogy in inservice teachers' classrooms.
- Preparation and commitment of preservice students to reform-based pedagogy.

Evaluation Questions

The three goals identified for the Grant Program were the source of questions by which we could evaluate the program during its first year.

1. What changes occurred in the preservice students' beliefs about mathematics teaching and learning?
2. What were the preservice students' perceptions regarding the course climate?
3. What were the preservice students' perceptions regarding the levels of camaraderie established with the Grant inservice teachers?
4. What changes occurred in the inservice teachers' beliefs about mathematics teaching and learning?
5. What were the inservice teachers' perceptions regarding the course climate?
6. What were the inservice teachers' perceptions regarding the levels of camaraderie established with the preservice students?
7. What levels of mathematics achievement were attained by Grant Elementary School students as measured by traditional assessments?
8. What levels of mathematics achievement were attained by Grant School students as measured by performance assessments?

Implicit in our goals for this project year were efforts to enhance the mathematical content knowledge of both the preservice students and the inservice teachers within the mathematics methods course that was offered. However, the goals of the course were primarily pedagogical. Therefore, measurement of potential gains in content knowledge was not part of the design of this study. Evaluation studies of subsequent implementation of the ongoing partnership project will address teacher growth in other domains related to mathematics education, including content.

Procedures and Findings

Although this study was not designed to be experimental in nature, two intact comparison groups served as benchmarks against which to compare the Grant Program on several important issues. For example, to address our research questions regarding preservice students, we compared data obtained from preservice students in the Grant Program with data from preservice students enrolled in two other sections of mathematics methods at the same institution during the same semester. These two sections were involved in similar content and methodology and a weekly field-based practicum, the major differences for the Grant preser-

vice students being the school-based location and involvement of inservice teachers in the course. All three sections consisted of demographically similar students who met the same admission standards for entrance into the institution's elementary education program.

The following presentation of procedures and findings is organized according to the questions listed in the previous section.

Question 1. What changes, if any, occurred in the preservice students' beliefs about mathematics teaching and learning?

To examine beliefs about mathematics teaching and learning, we used an online survey developed by Philipp, Ambrose, Lamb, Sowder, Schappelle, and Sowder, (2007) as our pre- and post-assessment. These researchers have identified the following seven beliefs that underlie reform-based classroom practice and have used these beliefs as the conceptual framework for their survey.

Beliefs About Mathematics

1. Mathematics is a web of interrelated concepts and procedures (school mathematics should be too).

Beliefs About Learning or Knowing Mathematics, or Both

2. One's knowledge of how to apply mathematical procedures does not necessarily go with understanding of the underlying concepts. That is, students or adults may know a procedure they do not understand.

3. Understanding mathematical concepts is more powerful and more generative than remembering mathematical procedures.

4. If students learn mathematical concepts before they learn procedures, they are more likely to understand the procedures when they learn them. If they learn the procedures first, they are less likely ever to learn the concepts.

Beliefs About Children's (Students') Learning and Doing Mathematics

5. Children can solve problems in novel ways before being taught how to solve such problems. Children in primary grades generally understand more mathematics and have more flexible solution strategies than their teachers, or even their parents, expect.

6. The ways children think about mathematics are generally different from the ways adults would expect them to think about mathematics. For example, real-world contexts support children's initial thinking whereas symbols do not.

7. During interactions related to the learning of mathematics, the teacher should allow the children to do as much of the thinking as possible. (p. 65)

The survey, entitled the *Integrating Mathematics and Pedagogy (IMAP) Web-Based Beliefs Survey* (2001), assesses the degree or intensity to which respondents possess the seven beliefs identified. The *IMAP Beliefs Survey* presents written or video cases to which teachers are asked to respond. The responses are then analyzed via rubrics based on three-, four-, or five-point scales that have been updated based on continuing research on the instrument (Philipp, personal communication, May 25, 2006). Inferences are made about the intensity of the beliefs held by those taking the survey. The following is an excerpt from the browse version of the survey available at http://www.sci.sdsu.edu/CRMSE/IMAP/pubs.html (IMAP: Integrating Mathematics and Pedagogy Publications/Presentations [Browse the Survey], retrieved December 18, 2007).

Leticia has 8 Pokemon cards. She gets some more for her birthday. Now she has 13 Pokemon cards. How many Pokemon cards did Leticia get for her birthday?

2.1). Do you think a typical first grader could solve this problem?

Yes

No

2.2). If a friend of yours disagreed with you, what would you say to support your position?

Here is another word problem. Again, read it and then determine if a typical first grader could solve it.

Miguel has 3 packs of gum. There are 5 sticks of gum in each pack. How many sticks of gum does Miguel have?

2.3). Do you think a typical first grader could solve this problem?

Yes

No

2.4). If a friend of yours disagreed with you, what would you say to support your position?

The survey was administered to all participants at

Table 1
Comparison of Pre- and Posttest Scores of Grant Program Preservice Students and Inservice Teachers on the IMAP Beliefs Survey

Belief–abbreviated	Group	Pre-mean	Post-mean	Effect Size	*df*	*t*-value	*p*
1. Math is an interrelated web (0-4)	Pre	2.21	2.31	.132	52	.49	.312
	In	.92	2.31	1.619	23	4.19***	.000
2. Procedural knowledge does not equate to conceptual understanding (0-5)	Pre	1.31	2.04	.776	52	2.82**	.003
	In	.83	1.62	.843	23	1.75*	.047
3. Concepts are more powerful than procedures (0-4)	Pre	2.41	2.68	.394	52	1.42	.081
	In	1.92	2.77	1.242	23	3.15**	.002
4. Children should learn concepts before procedures (0-4)	Pre	1.79	2.58	.827	52	3.00**	.002
	In	1.54	2.54	1.140	23	2.91**	.003
5. Children can solve problems before being taught how to solve them (0-5)	Pre	1.76	2.85	.944	52	3.49***	.000
	In	1.60	2.70	.837	23	2.11*	.023
6. Children think differently about math from what adults expect (0-5)	Pre	1.64	2.92	1.454	52	5.34***	.000
	In	1.70	2.90	1.251	23	1.72**	.003
7. Children should do as much of the thinking as possible (0-4)	Pre	.79	1.56	.749	52	2.73**	.004
	In	.62	1.33	.647	23	1.63	.058

*$p < .05$
**$p < .01$
***$p < .001$

the beginning and completion of the methods course. As mentioned in the introductory section of this paper, one of the intended outcomes of the program was to help inservice teachers create classroom environments that were friendly to reform perspectives in which preservice students could work. As alluded to previously, the influence of an inservice teacher upon a preservice student can be quite powerful and may even negate the influence of the mathematics methods course. Therefore, we were taking a risk by placing students in classrooms with teachers who were just beginning to examine their own practices in mathematics education. Thus we wondered, would the methods course in the Grant Program influence the beliefs of the preservice students as effectively as the other methods courses held at the same institution that were not part of the Grant Program?

First, pre and post means were compared using a series of *t*-tests to examine changes in the beliefs of the Grant Program preservice students toward a reform perspective. These analyses indicate that such changes occurred in five of the seven beliefs and are displayed in Table 1. (Table 1 also reports results of a similar analysis of the beliefs of Grant Program inservice teachers. These results are discussed later in this paper.)

Next, belief changes experienced by the preservice students in the Grant Program were compared to belief changes of students in the other two sections of mathematics methods (labeled in this paper as Comparison A and Comparison B groups). An analysis of covariance was used for this comparison to account statistically for pre-existing differences in belief intensity among groups. The Tukey-Kramer post-hoc procedure was then used to test for the degree of significance associated with specific group comparisons.

As shown in Table 2, no statistically significant differences in the belief changes experienced by the three groups of preservice students were observed, with two

Table 2
Results of Analysis of Covariance for IMAP Beliefs Survey Scores According to Group

Belief (abbreviated)	Group	Adjusted Mean	*df* (within)	*F*	*p*
1. Math is an interrelated web	Comparison A	2.08			
	Grant	2.35	88	2.09	.139
	Comparison B	2.53			
2.Procedural knowledge does not equate to conceptual understanding	Comparison A	1.39			
	Grant	1.94	86	1..94	.150
	Comparison B	1.46			
3. Concepts are more powerful than procedures	Comparison A	3.19			
	Grant	3.17	84	0.13	.874
	Comparison B	3.28			
4. Children should learn concepts before procedures	Comparison A	3.29			
	Grant	3.28	84	0.95	.389
	Comparison B	3.54			
5. Children can solve problems before being taught how to solve them	Comparison A	2.18			
	Grant	2.70	88	4.11*[a]	.020
	Comparison B	2.83			
6. Children think differently about math from what adults expect	Comparison A	2.85			
	Grant	2.86	85	0.00	.998
	Comparison B	2.85			
7. Children should do as much of the thinking as possible	Comparison A	0.72			
	Grant	1.31	88	3.73*[b]	.028
	Comparison B	1.02			

Tukey-Kramer post hoc test differences: between Comparison A and B only[a] and between Comparison A and Grant only[b], $p < .05$.

exceptions. These exceptions were (a) between the two comparison groups relative to Belief 5, and

(b) between Comparison A and the Grant group relative to Belief 7, in favor of the Grant group. Thus, in most instances, preservice students who were paired with inservice teachers in the methods course in the Grant Program and preservice students who were not part of the Grant Program appeared to experience similar changes in belief intensity.

2. What were the preservice students' perceptions regarding the course climate?

At the end of the course, the preservice students in all three groups—Comparison A, Grant, and Comparison B—were asked to complete a *Student Survey* designed by one of the researchers. This survey used a 5-point Likert scale (shown on the *y*-axis of Figure 1 as a scale with a minimum of 1 and a maximum of 5) to assess the climate of the methods course as well as the

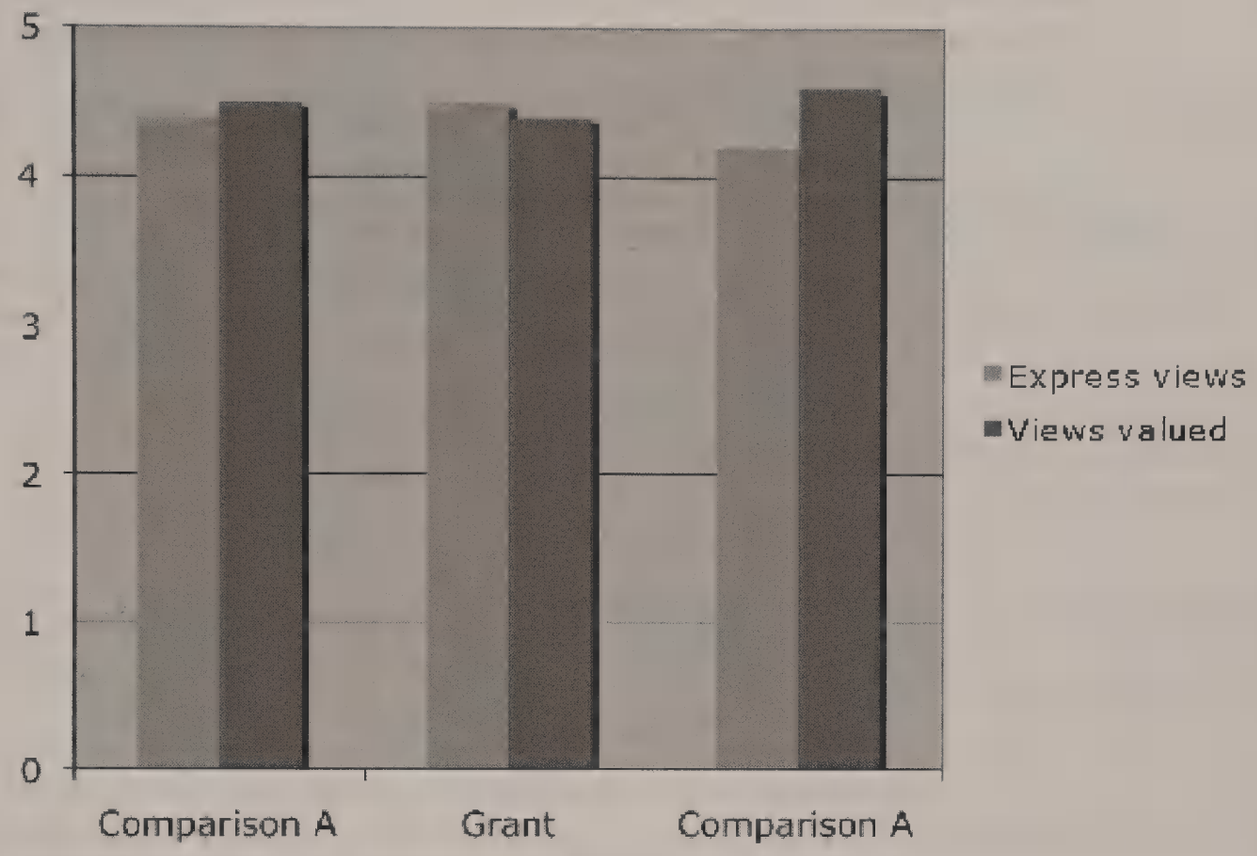

Figure 1. Preservice students' perceptions of classroom climate according to group as measured by the Student Survey.

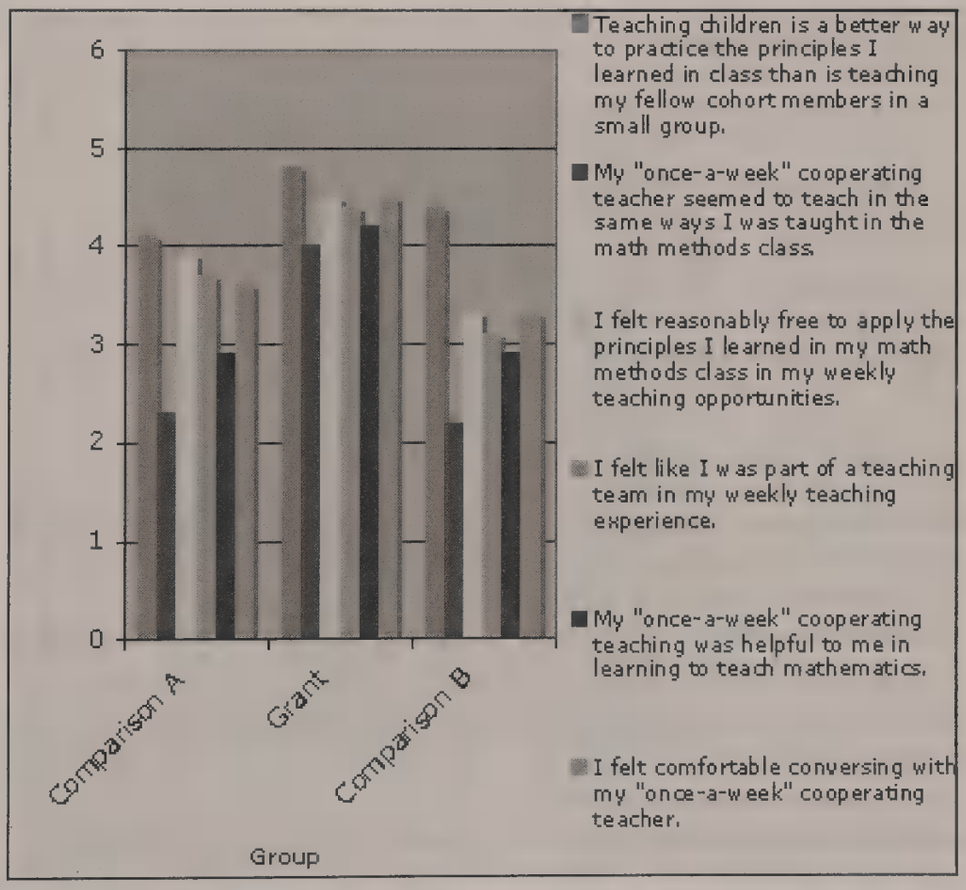
6
5
4
3
2
1
0
Comparison A
Grant
Comparison B
Group
Teaching children is a better way to practice the principles I learned in class than is teaching my fellow cohort members in a small group.
My "once-a-week" cooperating teacher seemed to teach in the same ways I was taught in the math methods class.
I felt reasonably free to apply the principles I learned in my math methods class in my weekly teaching opportunities.
I felt like I was part of a teaching team in my weekly teaching experience.
My "once-a-week" cooperating teaching was helpful to me in learning to teach mathematics.
I felt comfortable conversing with my "once-a-week" cooperating teacher.

Figure 2. Preservice students' perceptions of camaraderie with inservice teachers according to group as measured by the Student Survey.

Table 3
Results of Analysis of Variance for Perceptions of Camaraderie According to Group: Comparison A, Grant School, and Comparison B

Student survey item	Group	Adjusted Mean	*df* (within)	*F*	*p*
1. Teaching children is a better way to practice the principles I learned in class than teaching my fellow cohort members in a small group.	Comparison A	4.14			
	Grant	4.79	78	4.73*	.011
	Comparison B	4.43			
2. My "once a week" cooperating teacher seemed to teach in the same ways I was taught in the math methods class.	Comparison A	2.28			
	Grant	4.04	78	21.82***	.000
	Comparison B	2.21			
3. I felt reasonably free to apply the principles I learned in my math methods class in my weekly teaching opportunities.	Comparison A	3.93			
	Grant	4.43	78	8.82***	.000
	Comparison B	3.32			
4. I felt that I was part of a teaching team in my weekly teaching experience.	Comparison A	3.66			
	Grant	4.33	78	7.31***	.001
	Comparison B	3.07			
5. My "once-a-week" cooperating teacher was helpful to me in learning to teach mathematics.	Comparison A	2.96			
	Grant	4.21	78	8.33***	.001
	Comparison B	2.89			
6. I felt comfortable conversing with my "once-a-week" cooperating teacher.	Comparison A	3.55			
	Grant	4.45	78	5.71***	.005
	Comparison B	3.29			

*$p < .05$
**$p < .01$
***$p < .001$

preservice students' sense of camaraderie with the inservice teachers with whom they worked. Survey items 7 and 8 addressed course climate: "I felt comfortable expressing myself in my methods class" and "I felt that my views were valued in my methods class." Figure 1 graphically compares the responses of Grant Program preservice students to those of preservice students in the two comparison groups regarding these two items. Note that all groups' response levels are highly positive and quite similar, suggesting that involvement in the Grant Program did not negatively affect preservice teachers' perceptions of course climate.

3. What were the preservice students' perceptions regarding the levels of camaraderie established with the Grant inservice teachers?

The *Student Survey* also assessed perceptions regarding the level of camaraderie experienced by the preservice students through the use of six questions:

1. Teaching children is a better way to practice the principles I learned in class than is teaching my fellow cohort members in a small group.

2. My "once-a-week" cooperating teacher seemed to teach in the same ways I was taught in the math methods class.

3. I felt reasonably free to apply the principles I learned in my math methods class in my weekly teaching opportunities.

4. I felt like I was part of a teaching team in my weekly teaching experience.

5. My "once-a-week" cooperating teaching was helpful to me in learning to teach mathematics.

6. I felt comfortable conversing with my "once-a-week" cooperating teacher.

Figure 2 graphically compares their responses to those of preservice students in the two other methods course sections who had weekly methods-related field practica in other schools at which this type of project was not being conducted.

The responses were analyzed using a one-way analysis of variance. The mean response scores obtained by the preservice students involved at Grant School relative to all six survey items were significantly higher than those of the two comparison groups (see Table 3).

4. What changes occurred in the inservice teachers' beliefs about mathematics teaching and learning?

A comparison of means of pre-post scores obtained from the *IMAP Beliefs Survey* for Grant Program inservice teachers is included in Table 1. Statistically significant belief changes occurred; these changes were in the direction of beliefs that more closely approximate those of classroom teachers who implement reform pedagogy (Philipp et al., 2007).

Again using the *IMAP Beliefs Survey* as our measure, we compared the belief changes experienced by the Grant Program preservice students with those of the inservice teachers. (See Table 1.) Although both groups demonstrated changes in beliefs in the direction of reform-based pedagogy, the finding that inservice teachers demonstrated greater changes than did the preservice students is of particular interest and indicates a need for further study.

5. What were the inservice teachers' perceptions regarding the course climate?

During the methods course semester, the inservice teachers at Grant School were asked to complete a *Teacher Survey* designed by one of the researchers to parallel the *Student Survey* administered to the preservice students. This survey asked teachers to assess the climate of the methods course as well as their sense of camaraderie with the preservice students. Two questions addressed course climate: "I felt comfortable expressing myself in my methods class" and "I felt that my views were valued in my methods class." The Grant teachers indicated perceptions of course climate that were similar to those of the preservice students with whom they worked. (See Figure 3.)

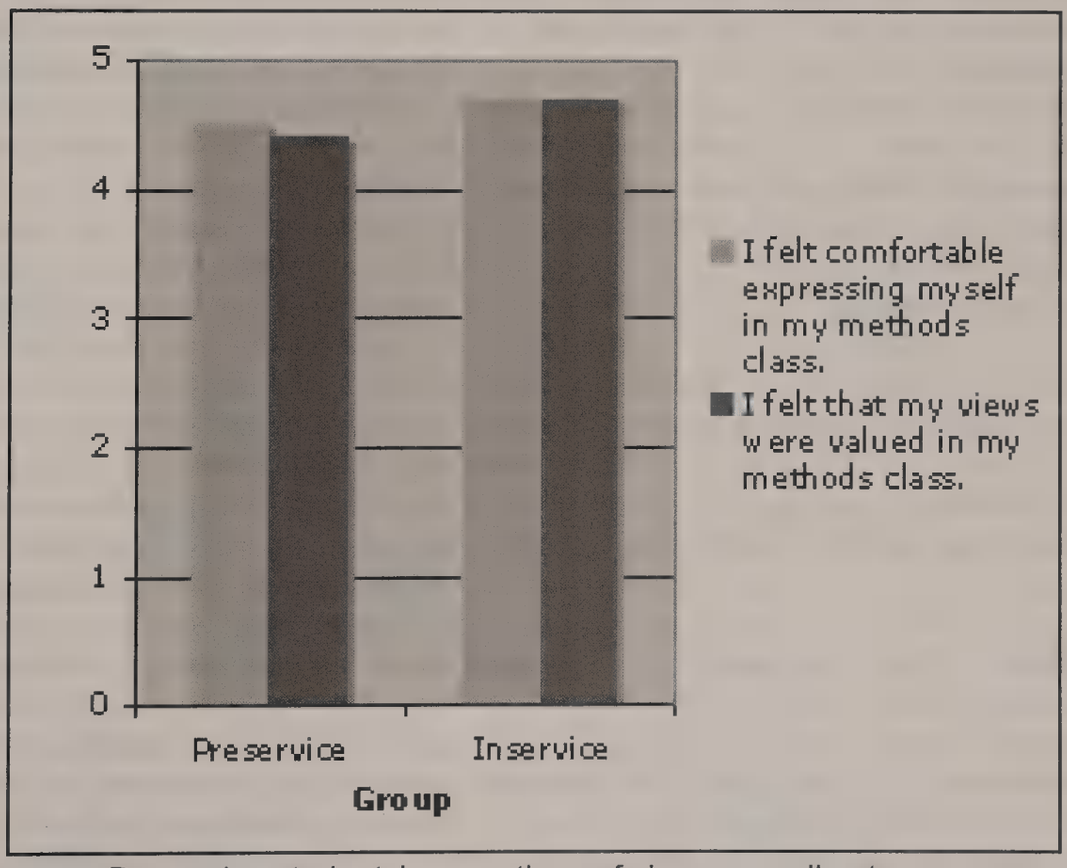

Figure 3. Grant Program: Preservice students' perceptions of classroom climate as measured by the Student Survey and inservice teachers' perceptions of classroom climate as measured by parallel items on the Teacher Survey.

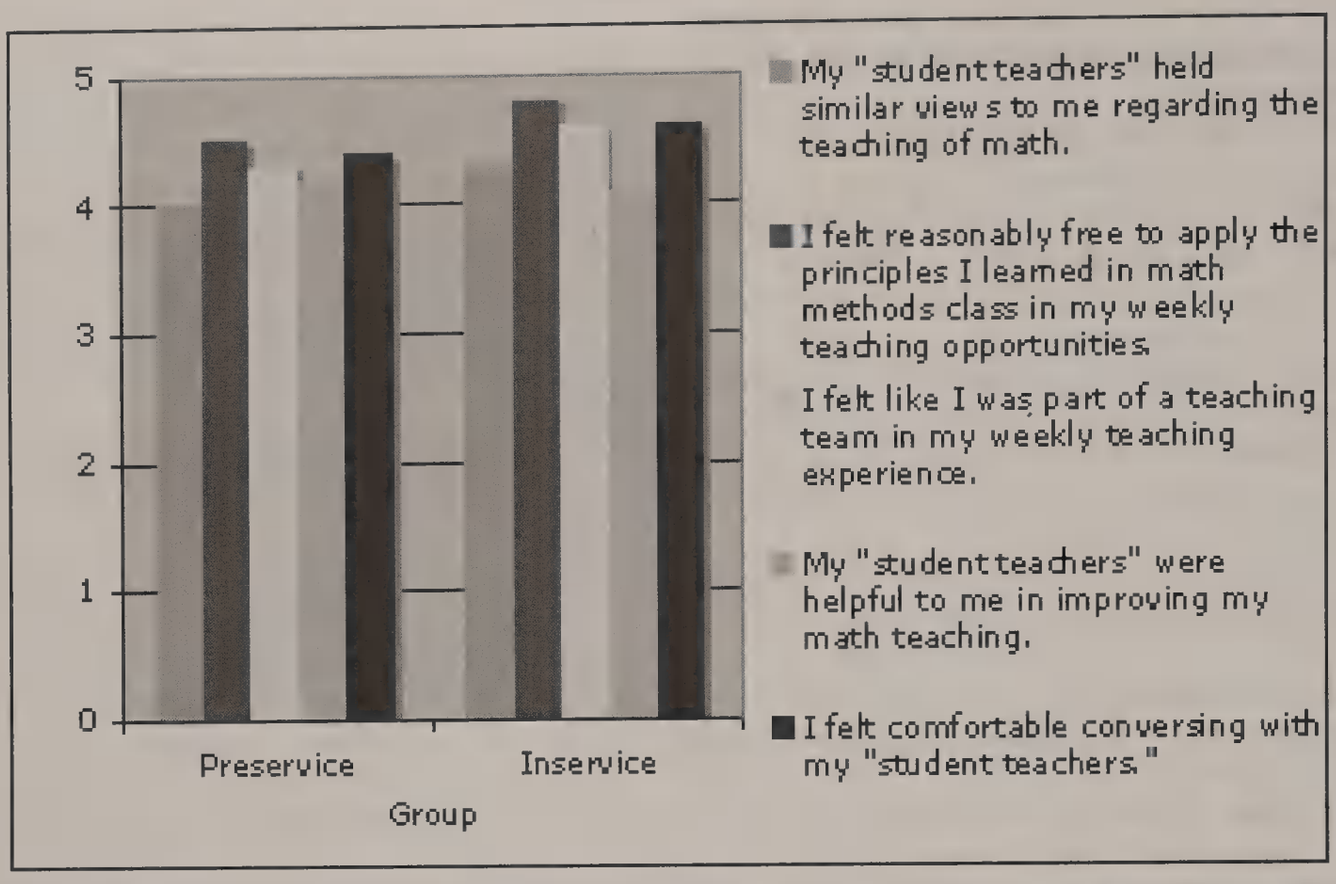
5
4
3
2
1
0
Preservice
Inservice
Group
My "student teachers" held similar views to me regarding the teaching of math.
I felt reasonably free to apply the principles I learned in math methods class in my weekly teaching opportunities.
I felt like I was part of a teaching team in my weekly teaching experience.
My "student teachers" were helpful to me in improving my math teaching.
I felt comfortable conversing with my "student teachers."

Figure 4. Grant Program: Preservice students' perceptions of camaraderie with inservice teachers as measured by the Student Survey and inservice teachers' perceptions of camaraderie with preservice students as measured by parallel items on the Teacher Survey.

6. What were the inservice teachers' perceptions regarding the levels of camaraderie established with the preservice students?

As mentioned in the previous section, the *Teacher Survey* also assessed perceptions regarding the level of camaraderie experienced by the inservice teachers through the use of the following five items:

"My 'student teachers' held similar views to me regarding the teaching of math."

"I felt reasonably free to apply the principles I learned in my math methods class in my weekly teaching opportunities."

"I felt like I was part of a teaching team in my weekly teaching experience."

"My 'student teachers' were helpful to me in improving my math teaching."

"I felt comfortable conversing with my 'student teachers.'"

Figure 4 graphically compares inservice teacher responses on this instrument to those of the preservice students. Note that the response levels for both groups were quite similar, suggesting that both experienced similar perceptions of camaraderie.

7. What levels of mathematics achievement were attained by Grant School students as measured by traditional assessments?

Student achievement from a traditional perspective was measured in two ways. First, the *Wide Range Achievement Test-3* (*WRAT-3*) (Stone, Jastak, & Wilkinson, 1995) was administered in the fall and the spring to all Grant School students, grades 1–5. This same measure had been administered to the students when they were in the previous grade, with two general exceptions. These exceptions were that (a) kindergartners were not tested using the *WRAT-3*, and (b) the *WRAT-3* had not been administered at the first grade level prior to the year under study. Gain scores were obtained by determining the differences in scores between these two measures for grades 3–5 when compared to gain scores of the same students during the previous grade. These scores were then analyzed using a *t*-test for paired samples (see Table 4).

Comparisons of *WRAT-3* scores indicate that students in the third and fourth grades demonstrated sig-

Table 4

Comparison of WRAT-3 Gain Score Means for the Year Under Study with Previous Year Gain Score Means for Grant School Students, Grades 3-5, Using a t-Test for Paired Samples

Grade Level	Previous Year Gain Score Mean	Year Under Study Gain Score Mean	*df*	*t*	*p*
3	5.03	5.66	25	4.44***	.000
4	5.77	6.65	22	6.34***	.000
5	5.17	3.38[a]	18	5.02***[b]	.000

[a]For fifth grade students for the year under study, the change in gain score mean was positive.
[b]However, when the gain score mean for fifth grade students for the year under study was compared with their previous year gain score mean, the gain score mean for the year under study was significantly lower.
***$p < .001$.

Table 5

Comparison of Scores on End-of-Level State Tests for Grant School Students, Grades 1-5

Grade Level	Previous Year Mean (%)	Year Under Study Mean (%)
1	93	98
2	85	87
3	85	87
4	85	91
5	79	80
Mean	85.8	89.8

nificantly greater growth during the year in which the program was being conducted than during the previous year. On the surface, the fifth grade comparison appears surprising. We anticipated observing similar gains among the fifth grade students when compared to gains made during their previous year. As shown in Table 4, the fifth grade scores showed the opposite trend: Significantly greater growth was experienced by students in the fifth grade during their fourth grade year, the year before the Grant Program began. As we considered reasons for this observation, we performed a content analysis of the *WRAT-3* items. This analysis revealed that in order for fifth grade students to make achievement gains comparable to those made in fourth grade, they would actually have to acquire math knowledge reflective of the sixth and seventh grade state curriculum.

The second traditional achievement measure consisted of the Utah State Office of Education end-of-level test administered at the end of each year. Scores obtained from the administration during the year under study were compared with scores obtained from the previous year; a summary is shown in Table 5.

Comparisons made at specific grade levels demonstrate a trend toward improvement, but the nature of typical end-of-level testing precludes establishing cause-and-effect relationships. As is true for most end-of-level testing (Kelly & Monczunski, 2007), the measurement items in this case were not held constant for the subjects as they moved from grade to grade. For example, the end-of-level test for fourth graders does not include the same items as the end-of-level test for fifth graders. However, the overall school means are quite impressive, thus allowing the observation that students at Grant School generally achieved higher scores on end-of-level tests for the year under study than for the previous year.

8. What levels of mathematics achievement were attained by Grant School students as measured by performance assessments?

Student achievement from an alternative assessment perspective was measured through the administration of a performance assessment to a small sample of students. This assessment was actually designed by the teachers themselves. It consisted of interviewing students regarding their conceptualizations of whole and decimal number sense and operation sense. Teachers carefully designed two word problems they considered

Table 6
Mean Rubric Scores for Number Sense (NS) and Operation Sense (OS) Performance Assessments

Grade Level	Rubric Scores: Problem Solving		Communication		Reasoning		Representing		Connecting		Procedural		Conceptual	
	NS	OS	NS	OS	NS	OS	NS	OS	NS	OS	NS	OS	NS	OS
1	3.45	3.50	3.55	3.60	3.40	3.55	3.50	3.40	3.60	3.65	3.90	3.20	3.40	3.75
2	3.77	3.50	3.67	3.67	3.60	3.64	3.70	3.50	3.70	3.71	3.90	3.40	3.60	3.82
3	3.29	3.10	2.59	2.47	2.60	2.41	3.10	2.60	2.30	2.35	3.10	2.80	2.30	2.12
4	4.00	3.20	4.00	3.00	4.00	3.00	4.00	3.20	4.00	2.00	3.80	3.80	4.00	2.60
5	3.68	3.84	3.16	3.84	3.40	3.84	3.70	3.60	4.00	2.63	3.20	2.30	3.60	3.89

Note. Rubric scores denote the following levels of performance:
4 independent performance
3 performance with limited teacher support
2 performance with significant teacher support
1 low quality performance despite teacher support

Table 7
Inter-rater Reliability Coefficients for Performance Assessments by Grade Level

Grade Level	Cronbach's Alpha: Number Sense	Operation Sense
Kindergarten	.932	.865
First	.711	.633
Second	.909	.846
Third	.806	.925
Fourth	.928	.881
Fifth	.915	.910

authentic for their students. They also prepared a set of 7-10 probing questions designed to help them assess their students' performance with regard to both conceptual understanding and procedural facility (Bransford, Brown, & Cocking, 1999; Kilpatrick, Swafford, & Findell, 2001) and the NCTM Process Standards – Problem Solving, Reasoning, Communicating, Representing, and Connecting (2000). The Process Standards provided the framework for assessment questions; they also served as the basis for evaluative criteria teachers used to design a rubric to quantify the degree of teacher support needed for students to complete the problems.

The teachers then interviewed a sample of their students individually, using the word problems they had designed as prompts. They probed student thinking through the use of the questions they had developed and scored the students' performance using the rubric. The results obtained from these assessments are summarized in Table 6.

Reliability of teachers' scoring was established during instruction on how to design and administer performance assessments. Videotaped assessment administrations were observed and scored by the teachers. Inter-rater reliability coefficients were then computed using Cronbach's Alpha and are displayed in Table 7. Despite the slightly lower correlations obtained from ratings associated with the first grade video, the ratings of these videotaped administrations clearly possess a high degree of inter-rater reliability and therefore suggest that the ratings obtained from the actual performance assessments would possess a similar level of reliability. Possibly the lower first grade ratings are a reflection of the challenge of assessing the thinking of younger children whose verbal skills are still underdeveloped. (A thorough discussion of the development of these assessments and of the inter-rater reliability associated with their administration is available in Bahr & Sudweeks, 2008.)

Conclusion

Our findings lead us to conclude that preservice students, inservice teachers, and elementary students were positively affected by the Grant Program during its first year. Preservice students experienced positive changes in their beliefs toward a reform perspective, were comfortable studying and applying mathematics methods alongside inservice teachers, and enjoyed camaraderie with those teachers. For inservice teachers at Grant School, similar belief changes also occurred, and these teachers indicated similar perceptions about their experience in the course and about working with preservice students. Finally, elementary students at Grant School experienced meaningful and substantive achievement as measured by both traditional and alternative assessments.

We believe that systemic change has been instigated as a result of the program. One of the benefits that should accrue from that change is that future preservice students who engage in field practicum experiences at Grant School will work under the mentorship of teachers who have spent considerable time studying and learning to apply reform-based pedagogy. We envision another study to ascertain the ongoing effects of our continued work at Grant School as well as at other public school sites.

One of the key limitations of our study relates to the interaction between program and personality. How much of the success of this program can be attributed to the quality of the professional relationships among the key players associated with its creation and implementation? Could this program be duplicated elsewhere without careful attention to the establishment of relationships of similar quality?

A second limitation relates to the sustainability of the observed effects. For example, teachers' belief systems tend to be deeply entrenched (Pajares, 1992), and even when teachers embrace new beliefs, they may not necessarily sustain that change or continue to change (Steinberg, Empson, & Carpenter, 2004). To what extent will the effects observed in the beliefs of preservice students translate into long-term reform-based instructional practice? Will similar belief changes observed among inservice teachers also result in similar long-term change in practice? In addition, when changes at the school occur, such as personnel or university partnership relationships, what will be the effects of those changes on mathematics teaching and learning at Grant School? The subsequent study we envision may serve to answer some of these questions.

Nevertheless, we agree with Liping Ma (1999) that focusing reform efforts in the direction of preservice teacher preparation will yield dramatic results over time. We further believe that coordinating preservice teacher preparation in mathematics education with the professional development of inservice teachers who supervise practicum experiences will serve to enhance the mathematics instruction provided by both groups. We also believe that public school–higher education partnership endeavors such as the Grant School Professional Development Program can serve to accelerate the reforms in mathematics education so necessary to the well-being of future students everywhere.

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Cosmology 101

Author: Kristine M. Larsen

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Westport CT 06881

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Hardback $49.95

Reviewer: Robert J. Whitaker
Missouri State University
Springfield, MO 65897

When early humans looked up into the sky, they saw the sun, moon, stars, and those "wandering" stars called planets. Questions soon arose. "Of what are these made?" "How far away are they?" "How do they move?" Various cultures offered various answers by invoking their god or gods. These "creation myths" proved satisfactory until such a time that an explanation of natural phenomena would be considered to be amenable to human reason.

The author, a professor of astronomy, emphasizes the way in which astronomers learn about the universe. She notes that astronomers cannot conduct experiments on the objects of their study. They cannot change the motion of any of these; they cannot "build" a star in a laboratory. All that they know about the celestial objects comes from observations of the light that comes from these. A major contribution to the study of the heavens came with the invention of the telescope. The invention of the spectroscope in the Nineteenth Century made possible the identification of the elements making up a star. This was supported by photography and is now being replaced by the electronic "charge-coupled device" or CCD. And large radio-telescopes provide information from long wavelength radiation.

The photographic study of stars at the end of the 19th and the first decades of the 20th century led to a system of spectral classification of stars by such luminaries as Annie Jump Cannon at Harvard. At this same time H. N. Russell of Princeton and Ejnar Hertzsprung in Denmark independently determined a relationship between the star's absolute magnitude (brightness) and its spectral class. The "HR-Diagram" is still a basic concept of modern astronomy. In this context the author then traces astronomers' attempts to construct theories to explain the structure of stars and that will account for their observations.

But innumerable stars of different sizes and properties are gathered together in huge galaxies. And billions of these galaxies extend enormous distances in all directions. Attempts to understand the beginning of the universe and the formation of stars and galaxies have generated several competing theories. Space precludes a meaningful discussion of these, but the debates among their respective proponents provides an interesting look at the interface between theory and observation and the way that "science works." We are provided with a look at the acquiring and interpretation of new observations, reinterpretation of older observations, development of new theoretical explanations, and the revision of older ones. Observational and theoretical cosmology are clearly active areas of scientific research.

A caveat on a couple of the author's historical references might be in order. Historians, who study the science of the Middle Ages, have eliminated the term, "dark ages," from their lexicon. Reference to the works of such historians as David Lindberg and Edward Grant would be appropriate. Similarly, Galileo was not "put on trial by the Inquisition for heresy," but for "vehement suspicion of heresy." While this may appear to be a trivial legalism, it was critical in the conduct of Galileo's trial and of its outcome. If mention of this is considered important, then reference to some of the recent scholarship (including useful documents published as a result of the recent Vatican Commission) would provide valuable nuances frequently absent in discussions of Galileo's controversies with his Church.

Larsen has produced a short, but comprehensive, account of modern cosmological thought along with its history. It concludes with a useful glossary and a selected, annotated list of references. While her book is intended for the general reader, the subject is challenging. However, it is clearly written and provides the interested reader with a useful introduction to a fascinating subject.

Electricity and Magnetism: A Historical Perspective (Greenwood Guides to Great Ideas in Science)
Author: Brian Baigrie

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88 Post Road West
Westport CT 06881

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Reviewer: Robert J. Whitaker
Missouri State University
Springfield, MO 65897

As the title suggests, *Electricity and Magnetism* is a history of the subject from ancient times to early Twentieth Century. It is intended for students as well as the general reader. The author carries the reader through effluvia and fluid theories of electricity and of magnetism. These include, for example, the two fluid concept of Dufay and the one fluid idea of Franklin. Volta's electric "pile" made possible a continuous source of "electricity." The relationship between electricity and magnetism, discovered by Oersted and theoretically explored by Ampere, leads to the work of Faraday. The discussion concludes with a brief look at the theoretical exposition by Maxwell and the later exploration of "cathode rays," "x-rays," and "electrons." In all, this is an ambitious work that covers considerable ground in a fairly short space.

A few misprints should be mentioned. Miletus, the home of Thales, was located on the coast of Asia Minor across the Aegean from the Greek peninsula. In the references, the author of *The De Magnete of William Gilbert* should be Duane H. D. Roller; and "The Development of the Concept of Electric Charge," Case 8 of the *Harvard Case Histories in Experimental Science*, co-written with his father, Duane Roller, is missing from the references.

The acceptance and use of Franklin's lightning rod is far more complex (and interesting) than the author presents. Opposition to its use was partially the result of the widely held idea that lightning caused earthquakes; thus, the fear that lightning rods on many buildings in a city would lead to an increased hazard from earthquakes. This opposition requires a much more nuanced approach such as was given by I. Bernard Cohen in his *Benjamin Franklin's Science* (listed in the Bibliography). Thus, the author's statement, regarding the destruction of a church and much of the city of Brescia, Italy, that the "... disaster impelled the Roman Catholic Church to abandon the religious objection to using lightning rods to protect property" cannot be justified by the contemporary evidence. And, the lightning rod provides us with the first instance of science guiding the invention of a technological device.

The author also distracts from the historical account at times by introducing modern explanations. For example, when discussing Coulomb's experiment to determine the nature of the force between two "charges," he includes a paragraph stating the modern, textbook statement of "Coulomb's Law," including modern units. Similarly, the author introduces the modern concepts of protons and electrons to explain the Voltaic pile and of the pile's later use to aid in the understanding of "chemical bonding." Finally, while the author notes that the use of modern vector notation in the description of Maxwell's theory is different from his original presentation, this use distracts from its history.

In the few places in which the author includes citations they seem to be to the 1895 work by Park Benjamin. A great deal of important historical research on the subject has been done since that time, and the history of science has matured as a discipline. Thus, in his bibliography, one might wish for some additional aid. Several classic works, such as Gilbert's *de Magnete* are available in translation. The edition of *The Papers of Benjamin Franklin*, begun in 1959, is superior to the one cited. L. Pearce Williams' definitive biography of Faraday; three valuable accounts of Thomson and the "electron," published in 1997 in conjunction with the centenary of its "discovery;" and Millikan's *The Electron* are missing.

This is an attractive volume, and the plates from classic works are clearly reproduced. It has a useful (if limited) bibliography and event timeline. Its broad scope of topics and the restricted number of pages, however, prevents a more comprehensive and in-depth historical analysis of the subject. That the history of science might guide a reader past the idea that this history is merely a chronology of events and theories that are judged in terms of today's understanding should be paramount in any such work. Unfortunately, the author has only partially succeeded, and the price may deter many readers for whom this work is intended.

PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to: Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel; or fax to:972-86-477-648. Questions concerning proposals and/or solutions can be emailed to: eisenbt@013.net. Solutions to previously stated problems can be seen at: ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before June 15, 2009

5062: *Proposed by Kenneth Korbin, New York,NY.*
Find the sides and the angles of convex cyclic quadrilateral ABCD if
$\overline{AB} = \overline{BC} = \overline{CD} = \overline{AD} - 2 = \overline{AC} - 2.$

5063: *Proposed by Richard L. Francis, Cape Girardeau, MO.*
Euclid's inscripbed polygon is a constructible polygon inscribed in a circle whose consecutive central angle degree measures form a positive integral arithmetic sequence with a non-zero difference.

a) Does Euclid's inscribed n-gon exist for any prime n greater than 5?
b) Does Euclid's n-gon exist for all composite numbers n greater than 2?

5064: *Proposed by Michael Brozinsky, Central Islip, NY.*
The Lemione point of a triangle is that point inside the triangle whose distances to the three sides are proportional to those sides. Find the maximum value that the constant of proportionality, say λ, can attain.

5065: *Proposed by Mihály Bencze, Brasov, Romania.*
Let n be a positive integer and let $x_1 \le x_2 \cdots \le x_n$ be real numbers. Prove that

$$1)\sum_{i,j=1}^{n}\left|(i-j)(x_i-x_j)\right| = \frac{n}{2}\sum_{i,j=1}^{n}\left|x_i-x_j\right|.$$

$$2)\sum_{i,j=1}^{n}(i-j)^2 = \frac{n^2(n^2-1)}{6}.$$

5066: *Proposed by Panagiote Ligouras, Alberobello, Italy.*
Let a, b, and c be the sides of an acute-angled triangle ABC. Let $abc = 1$. Let H be the orthocenter, and let d_a, d_b, and d_c be the distances from H to the sides BC, CA, and AB, respectively. Prove or disprove that

$$3(a+b)(b+c)(c+a) \ge 32(d_a+d_b+d_c)^2.$$

5067: *Proposed by José Luis Díaz-Barrero, Barcelona, Spain.*
Let a, b, c be complex numbers such that $a + b + c = 0$. Prove that

$$\max\{|a|,|b|,|c|\} \le \frac{\sqrt{3}}{2}\sqrt{|a|^2+|b|^2+|c|^2}.$$

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This paper discusses the experience of a preservice secondary mathematics teacher during lesson study. Although the preservice teacher was a strong undergraduate mathematics student, she used compensation "moves" to deflect attention away from her insecurities about her conceptual understanding of secondary mathematics. She feared being labeled as "dumb" and redirected conversations in order to protect her identity as a knower of mathematics. This paper investigates the culture in which preservice teachers develop confidence in their personal mathematics knowledge and how that confidence may influence behavior.

A Case Study of Three Children's Original Interpretations of the Moon's Changing Appearance

Jennifer Wilhelm

A case study of three children was conducted to shed light on the process that children undergo in developing their understanding of physical phenomena. Using the notion of spontaneous construction and its relationship with school learning of scientific concepts, children's early thoughts of the moon's appearance were explored. Research questions were primarily concerned with how children view the moon's appearance, explain how and/or why its appearance changes, quantify the moon's size and its distance to Earth, and explain the moon's illumination. A Piagetian interview was conducted with each child and then each was asked to tell a story about the moon. The external interest of this research study involves when and why do children develop the commonly held Earth's shadow alternative conception as the cause of the moon's phases. The findings show that children have stories and experiences that give meaning to the existence of such things as the moon, stars, sun, and clouds. Similarities were found in the children's interpretations with regard to their natural tendencies to animate celestial objects. Clues were discovered of cultural influence such as family, personal observations and experiences, books, pictures, car travel, and even a strategically placed Palladian window.

Understanding of Earth and Space Science Concepts: Strategies for Concept Building in Elementary Teacher Preparation

Nermin Bulunuz, Olga S. Jarrett

This research is concerned with preservice teacher understanding of six earth and space science concepts that are often taught in elementary school: the reason for seasons, phases of the moon, why the wind blows, the rock cycle, soil formation, and earthquakes. Specifically, this study examines the effect of readings, hands-on learning stations, and concept mapping in *improving* conceptual understanding. Undergraduates in two sections of a science methods course (N=52) completed an open-ended survey, giving explanations about the above concepts three times: as a pretest and twice as posttests after various instructional interventions. The answers, scored with a three point rubric, indicated that the preservice teachers initially had many misconceptions (alternative conceptions). A two way ANOVA with repeated measures analysis (pretest/posttest) demonstrated that readings and learning stations are both successful in building preservice teacher's understanding and that benefits from the hands-on learning stations approached statistical significance. Concept mapping had an additive effect in building understanding, as evident on the second posttest. The findings suggest useful strategies for university science instructors to use in clarifying science concepts while modeling activities teachers can use in their own classrooms.

Using Metaphors as a Tool for Examining Preser-

vice Elementary Teachers' Beliefs About Mathematics Teaching and Learning

Stacy Reeder, Juliana Utley, Darlinda Cassel

This study used metaphors as a tool to gain insight about preservice teachers' conceptualizations of the role of the teacher and the learner and held the view that the examination of these metaphors might provide an opportunity for teacher educators to reflectively and critically examine those beliefs. Thus, this research examined possible differences in the reflected beliefs of elementary preservice teachers as depicted in their metaphors about mathematics teaching and learning at three different points throughout their mathematics education methods courses. The results of this study indicated that elementary preservice teachers' beliefs primarily remained static throughout their mathematics methods courses despite ongoing experiences designed to challenge and extend those beliefs.

Research in the Classroom

Mathematical Habits of the Mind for Preservice Teachers

Tim Jacobbe, Richard S. Millman

This article provides an overview of mathematical habits of the mind and discusses how the concept relates to Polya's problem solving principles as well as exemplification. Specific problems are discussed as a means to assist preservice elementary school teachers' in their development of mathematical habits of the mind. Without a technique to begin solving these rich problems, preservice teachers may have difficulty getting started. The process of preservice teachers outlining their thinking as they progress through Polya's process is discussed. Students' reflections from this technique are discussed to explore the outcomes that may be expected from establishing an environment where students are encouraged to develop mathematical habits of the mind.

editorial

Joel Kirschbaum
Desert Hot Springs, CA

Teaching the Pros and Cons of Evolution in the 21st Century

The ability of administrators and policymakers to discourage public school science teachers from presenting the objective evidence for evolution is continuing. We all know that the past barring of the theory of evolution from the classroom is now illegal. But then the idea of "intelligent design" was introduced as an alternative theory. This scientifically discredited theory of the origin of life was examined in court and now cannot be legally taught in most public schools. However, believers in biblical creation want educational "balance" by asking teachers to include either the controversies or the weaknesses of evolution when its strengths are taught. This editorial emphasizes 21st century data supporting evolution and also presents the scientific "cons" to the theory. Current evidence is essential because many believers in the special creation of life on Earth impose artificial interpretations on older archeological, embryological, and anatomical evidence for evolution. For example, they consider dinosaur bones to be merely a few thousand years old and to be the by-products of Noah's flood. To biblical fundamentalists, fossils must be forced to follow faith, not facts.

The major anti-evolution arguments involve the origin of complex molecules and cells. However, experiments have shown that many simple bio-chemicals can be synthesized using the likely atmosphere and catalysts thought to exist on an early Earth. Still to be replicated in the laboratory is the formation of macromolecules like DNA, RNA, and proteins from these simple precursors. In addition, evolutionary scientists need to produce the mechanisms of how DNA and RNA evolved reproduction, and came to be packaged in cells. Also unknown is how cells evolved reproducible replication, assembly, specialization, and, of great importance; how one or more cells can send signals or messages to other cells, which then respond. These are all questions about what happened at the beginnings of life. This problem is shared by astrophysicists who are questioned both about what existed before the "big bang", and what happened just afterwards.

Before considering the modern evidence for evolution, we must mention that radioactivity, the basis of both nuclear weapons and some medical treatments, proves conclusively that the Earth is old enough for evolution to occur. The decay of a chain of both short- and extremely long-lived isotopes (as measured using equipment like mass spectrometers which are familiar to viewers of true-crime TV programs) shows the Earth to be about five billion years old. These eons of existence show that there was sufficient time for humans to evolve.

The probability of life occurring is analogous to the frequency of one golfer hitting two holes-in-one in one week. The reason that this rare event can happen is that millions of golfers daily are playing 18 holes worth of balls. Similarly, there were many chances for life to originate because there are about a hundred billion suns in our galaxy and billions of galaxies in a universe dated to be about 14.7 billion years old. About 30% of observed suns have planets, as shown by side-to-side solar wobbles due to the pull of gravity on the sun by an orbiting planet. So life on our planet is a rare but not statistically impossible event!

The all-important, overwhelming argument for evolution is DNA. This molecule, and its related cousin RNA, provide the genetic links all life lies along, as well as the means of mutation and the mechanism for evolution to occur. It also provides a tool for identifying the degree of relatedness of all biological organisms that have ever lived, including humans. For example, consider the situation where DNA is found at a crime scene. All humans have 99.9% similar DNA but different individual's DNA can be distinguished from each other. The police get DNA samples to compare with those that are identical to DNA already on file from a felon. They also obtain DNA from family members in order to eliminate or identify them as possible suspects. Every criminal cold case solved is another point proving evolution. So far, DNA evidence has freed from death row more than 40 prisoners who

were wrongly sentenced to be executed. Incidentally, a well-known governor recently signed a bill increasing funding for DNA studies in state criminology labs but, paradoxically and illogically, the governor publicly rejects evolution.

Evolution doesn't propose that monkeys are our great grandparents - only that we have common ancestors. DNA studies show that the further removed in lineage one creature is from another, the more dissimilar is the DNA. The primate, who has 98.5% of its DNA in common with humans, is eating a banana that is about 25% related to human DNA. Indeed, there are no controversies about evolution among objective thinkers. For example, the false demand to produce "intermediate species" was easily dismissed because no present-day species is the ancestor of any other. We also now understand the evolution of such complex structures as the skull, eye and the three-bone cochlear apparatus, as well as the interrelatedness of the molecules involved in blood-clotting. The continuous expansion of our understanding of these and other biological structures provides mounting evidence that evolution is a sound theory that all students should learn.

RESEARCH IN
brief

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Problem Posing and Problem Solving: A Dynamic Connection

The study of mathematical problem posing has become an important area of investigation by researchers in mathematics education (English, 1997a, 1997b; Kilpatrick, 1987; Silver, 1994; Silver & Cai, 1996). Problem posing, with its emphasis on having students generate and develop their own mathematical problems from particular situations or on the basis of their prior problem solving experiences, may be an important activity that in fact helps students develop as inquiry-based problem solvers.

Proponents of problem posing advocate for the inclusion of problem posing as part of the mathematics curriculum for several reasons. These include the view that problem posing involves the process of reflection to consider imagined mathematical activity (Goldin, 1987; Schoenfeld, 1994; Thompson, 1994), a type of self-generated activity that may stimulate the students' overall abilities to mathematize and develop understanding within new situations. In addition, there is widespread optimism that having students reflect on their mathematics in order to pose new problems may help them become better problem solvers. Hence, posing problems is viewed by many as a useful classroom activity that may help nurture the mathematical thinking, and particularly, the problem solving actions of students.

The exemplary research on problem posing has been reported in a series of studies by English (1997a, 1997b) and Silver and his colleagues (Cai, 1998; Silver, 1994; Silver & Mamona, 1989; Silver & Cai, 1996; Silver & Stein, 1996). For example, English designed a comprehensive framework for developing young children's mathematical problem posing (English, 1997a) and assessed the effectiveness of using problem posing in middle grades classrooms (English, 1997b). In addition, Silver and his colleagues conducted studies of problem posing that encompass a range of important issues related to problem posing, including studies of the problem posing activities of Middle Grades students (Silver & Cai) and in-service teachers (Silver & Mamona), and the effectiveness of problem posing within a contemporary Middle Grades mathematics curriculum (Silver & Stein).

While these studies have undoubtedly added to our knowledge of problem posing as a mathematical activity, the research is less certain concerning the specific roles that problem posing plays in problem solving situations. A particular issue concerns the ways that problem posing and problem solving interact while a student is in the process of solving a problem. In what ways do the solver's initial problem formulations impact on his/her solution activity? Students may view the problem in a particular way that influences the goals he or she sees fit to develop and pursue. For example, he or she may look to break down or reduce the original problem into smaller problems, the solution of which lead to a solution of the original problem. Research studies that examine how the students' personally constructed problems lead to appropriate solution activity would enable mathematics educators at all levels to better understand the diverse reasoning actions of students.

Conversely, in what ways do the solver's results of carried out solution activity help him or her to re-formulate the current problem or pose additional problems? For example, students engaged in the solution of a problem may generate a result that challenges or calls into question their prior goals and actions. In these situations the ways that the student acts to resolve the new question often leads to a reformulation of the original problem which may in turn lead to progress in finding a solution. While studies of college students have documented this recursive property of problem solving, involving successive and on going reformulations of problems (Carlson & Bloom, 2005; Cifarelli & Cai, 2005), studies are needed that examine the development of this process in K-12 settings.

The discussion presented here suggests how problem posing connects naturally to the solver's on going development of solution activity in problem solving sit-

uations and thus suggests some important issues for researchers to consider about the role of problem posing in problem solving. Studies are needed that examine these natural connections between the problem posing and solving actions of solvers.

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A Preservice Secondary Teacher's Moves to Protect Her View of Herself as a Mathematics Expert

Julie Stafford Plummer
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This paper discusses the experience of a preservice secondary mathematics teacher during lesson study. Although the preservice teacher was a strong undergraduate mathematics student, she used compensation "moves" to deflect attention away from her insecurities about her conceptual understanding of secondary mathematics. She feared being labeled as "dumb" and redirected conversations in order to protect her identity as a knower of mathematics. This paper investigates the culture in which preservice teachers develop confidence in their personal mathematics knowledge and how that confidence may influence behavior.

In 1990, Ball reported that preservice secondary teachers explained mathematics concepts procedurally rather than addressing underlying mathematics principles. This tendency led teacher candidates to possess three beliefs, namely, that secondary school mathematics lacked difficulty, that the mathematical knowledge needed to teach secondary mathematics was gained prior to college, and that any additional knowledge needed was acquired while studying undergraduate mathematics (Ball). These beliefs leave teacher candidates to feel confident in their secondary mathematics knowledge (Meredith, 1993). Even with this confidence, researchers (Ball; Borko, Eisenhart, Brown, Underhill, Jones, & Agard, 1992; Cooney, 1999; Mewborn, 2003) report that prospective mathematics teachers exhibit weak secondary mathematics knowledge.

This paper describes the case of Janica, a preservice mathematics teacher with a strong and successful undergraduate mathematics background who felt quite confident about her knowledge of high school mathematics. The context for this research is a lesson study experience as part of her mathematics teaching methods class. As she interacted with her peers, some weaknesses in Janica's understanding of high school mathematics began to surface. This paper seeks to describe Janica's experience in her lesson study group and how she dealt with her emerging knowledge of her weaknesses.

Literature Review

Cultural beliefs about teaching and learning mathematics

Stigler and Hiebert (1999) defined teaching as an activity possessing cultural scripts that are "learned implicitly, through observation and participation and not by deliberate study" (p. 86). Members of a culture assimilate and perpetuate cultural norms as they act within the culture. Therefore, after years of participation in the mathematics classroom, preservice teachers acquire beliefs about such things as student learning, the instructor's role, and their subject matter (Clark, 1988; Cooney, Shealy, & Arvold, 1998; Smith, 2005). These cultural scripts are furthermore reinforced as prospective teachers spend time in the mathematics classroom through practicum and other teacher education courses (Cooney, 2001). In the United States teacher candidates adopt the belief that the teacher is the mathematics authority in the classroom and perpetuate this belief following completion of teacher education (Stigler & Hiebert, 1999). When one compares this to Japan, new teachers in Japan "are considered to be novices who need the support of their experienced colleagues" (Shimizu, 1999, p. 111). Stigler, Fernandez, and Yoshida (1996) suggest that in Japan teaching is viewed "more as a craft… that can be perfected through practice" (p. 216) whereas in the U.S. teaching is viewed as an inherent quality. With the enactment of No Child Left Behind (NCLB), the need for "highly-qualified" U.S. teachers was addressed; however, the implementation of NCLB has encouraged the idea that U.S. teachers are sufficiently prepared to teach after solely performing well on "rather narrow subject-matter tests" (Berry, Hoke, & Hirsch, 2004, p. 686). The U.S. teacher education community asserts that something must be done to support and facilitate teacher learning beyond the preteaching years (Hill & Ball, 2004), however, currently no widespread system exists in the U.S. Few provisions are made for in-service teachers to improve their mathematical understandings and knowledge in tandem with teaching. This leaves U.S. teachers trapped in a system that prevents them from admitting weaknesses in mathematical knowledge and improving upon their teaching

knowledge.

A specific U.S. example comes from a preservice mathematics teacher, Ms. Daniels, and how she responded to a division of fractions teaching episode. In the episode, Ms. Daniels struggled to respond to a student's question about why you invert and multiply, however "she was basically pleased with the lesson" (Borko et al., 1992, p. 198). Borko et al. claimed that Ms. Daniels' beliefs, similar to those cited by Ball (1990), "probably interfered with her ability to recognize that she did not have the subject matter knowledge necessary to implement her beliefs about good teaching" (p. 218).

Wagner, Lee, and Ozgun-Koca (1999) studied the self-confidence and attitudes of preservice mathematics teachers in Turkey, Korea and the United States. They found that "although preservice mathematics teachers from all three countries have self-confidence in teaching mathematics and positive attitudes towards mathematics, U.S. preservice mathematics teachers have more self-confidence and stronger beliefs" (p. 6) than preservice teachers in other countries. The possible origins of this self-confidence are described by Stevenson, Lummis, Lee, and Stigler (1990) who stated that U.S. "achievement is attributed to innate ability" (p. 23), whereas in other cultures (e.g., Japan) achievement is attributed to personal effort. This perspective influences how a culture views successful mathematics students. When students are successful, they must have natural ability and thus their confidence in their mathematical knowledge is bolstered. Williams and Montgomery (1995) found that when a U.S. student outperformed fellow students, the individual reported a "high mathematics self-concept" (p. 401), and there was a high correlation between how students performed in mathematics and how the community perceived their natural ability. Similarly, math self-concept has a high correlation with a person's math achievement (Chiu, 2008).

With this confidence in one's mathematical knowledge and ability, how might a preservice teacher act if placed in a situation where some mathematical weaknesses were exposed? In order to examine the correlation between this stated confidence and actions, we look to the literature on the coherence of beliefs.

Coherence of Beliefs and Actions

A member of a culture typically assumes the culture's beliefs. With regard to teachers, those beliefs and views impact instructional behavior (Thompson, 1984). For researchers this translates into the idea that investigating behavior could expose the beliefs that initially motivated a teacher's actions. However, this is not an easy task when a teacher's stated views of teaching seem at odds with teaching behavior. Leatham (2006) pointed out that often researchers are "assuming that teachers can easily articulate their beliefs and that there is a one-to-one correspondence between what teachers state and what researchers think those statements mean" (p. 91). Researchers attempting to investigate a teacher's beliefs may consider the beliefs and actions as inconsistent when the behavior plays out differently than the researcher expected. The inconsistency, however, may rest with the researchers' interpretation of data and not with the teacher.

To address this issue in this research, the researchers espouse Leatham's (2006) theoretical and methodological *sensible system* framework for beliefs as the foundation for this study. The theoretical aspect of the *sensible system* framework of beliefs defines beliefs as things individuals may "just believe" or are "more than believe – we know," the latter is specially termed knowledge (Leatham, p. 92). These beliefs are organized into a system that makes sense to the individual and in turn influences behavior. The methodological aspect of this framework implies that researchers must examine and discover, through inference, the sense in the individual's belief system because the system does not exist or operate in a contradictory state. When inconsistencies appear to emerge, this is a good place for researchers to probe further. Acting in tandem with the *sensible system* framework, coherence theory states that a person's comments and actions are consistent within the individual's belief system (Alcoff, 1996). The challenge, then, is to see how they sensibly fit within the subject's interpretation of the world.

Highlighting the influence of beliefs on actions, Siebert, Lobato, and Brown (1998) reported on teacher candidates who assimilated their teacher education experiences. One teacher candidate, Antonio, utilized compensation moves to avoid reassessing his fragmented mathematics knowledge. Even though Antonio was introduced to the rich meanings imbedded in the concepts, he ignored their significance and instead claimed that "meaning can be found in procedures" (Siebert et al., 1998, p. 622). In this situation of conflict, Antonio tailored his "conceptual ideas to fit [his] framework of beliefs" (Schram & Wilcox, 1988, p. 354).

This preceding example shows how Antonio organized information within his belief system in a way that

made sense to him and in turn influenced his actions. This interplay and coherence between beliefs and actions described in the research will provide a lens through which the researchers can look at the actions of a preservice teacher who stated confidence in her mathematical knowledge and ability.

Summary

The researchers acknowledge that preservice teachers will act in accordance with their belief systems in ways that make sense to them. As members of the teaching culture, U.S. preservice teachers accept the cultural belief that they will be the mathematical authority in the classroom. This is sustained by the culture's view that because preservice teachers are majoring in mathematics they have "innate ability," and following teacher education, are sufficiently prepared to teach secondary mathematics. However, future secondary teachers' mathematics knowledge is often fragmented and fragile. Therefore, preservice teachers may face a conflict between their fragmented knowledge and these cultural expectations if they recognize the limitations of their knowledge.

It was the purpose of this study to place preservice teachers who have confidence that they are experts in secondary mathematics in a setting where they would discuss, in detail, the mathematical content of a secondary mathematics lesson. This situation was created when preservice teachers prepared a lesson on logarithms in the context of Japanese lesson study. Thus the research question was "how does a preservice teacher, who expresses confidence in her secondary mathematics knowledge and ability, respond when faced with the reality that her mathematics knowledge is fragile and fragmented?"

Research Design and Methodology

Because the research question focused on confidence and mathematics knowledge of preservice teachers in an open dialogue setting, the researchers chose a case study methodology. This allowed the researchers to be "explicitly mindful" of the goal of the study while being open to new or unexpected findings (Miles & Huberman, 1994).

Context

The context of this study was a secondary mathematics teaching methods course at a large private university where one author was the instructor and the other was a graduate research assistant (GRA). One of the elements of the methods course was for the students to participate in Japanese lesson study. Thus, we will first describe lesson study and then the class structure in which it was placed.

Lesson Study

Stigler and Hiebert (1999) describe lesson study as the commonly used method of professional development in Japan. They state, "In lesson study, groups of teachers meet regularly over long periods of time…to work on the design, implementation, testing, and improvement of one or several 'research lessons'" (p. 110). In lesson study "competing views of teaching bump against each other" and possibly have an influence on "content knowledge development" (Lewis, 2000, p. 17). Therefore, this practice could be fertile ground for investigating teachers' mathematical understandings.

The basic lesson study format, drawn from Stigler and Hiebert (1999), Lewis (2000, 2002), and Fernandez, Chokshi, Cannon, and Yoshida (2001), is:

1. *Goal Setting*
2. *Planning*
3. *Teach Research Lesson*
4. *Revise*
5. *Teach Research Lesson a 2nd time*
6. *Report*

Class Structure

The study participant was enrolled in a secondary mathematics teaching methods course at a large private university where one author was the instructor and the other was a graduate research assistant (GRA). The course textbook was a compilation of chapters from public school textbooks ranging from pre-algebra through second year algebra. Each preservice teacher had the opportunity to teach two lessons from this textbook while the peer group role-played the appropriate grade level.

The authors created lesson study groups midway through the semester; these groups met to plan a lesson for public school students. Each group, guided by a public school teacher, selected a goal for their research lesson. Once the lesson goal was selected, each group met for approximately two hours a week to refine their lesson. After two weeks of planning, one member of the group taught the lesson to their peers. The remainder of the group observed the lesson and watched how their peers responded to the learning activities. The lesson continued to be refined for another six weeks until another group member taught the lesson in a public school classroom. Each group then wrote a report on the lesson development and the public school students' responses to the lesson.

Participants

In order to divide the class into lesson study groups, the researchers analyzed student data from responses to a Likert-scale survey and two open-ended questions, "What is mathematics?" & "How do you learn mathematics best?" The researchers focused on two issues during analysis: 1) the level of confidence the student reported on the statement: "I would consider myself an expert when it comes to secondary mathematics" and 2) whether the student seemed to view and learn mathematics conceptually or procedurally. Of course strict classification without overlap was impossible, however, the most dominate views, of self and mathematics, were noted. The group from which the study participant was selected consisted of students who had a variety of perspectives and had shown that they were comfortable expressing themselves verbally.

Data Collection

Instruments utilized in the data collection process included a weekly dialogue journal, field notes taken during the methods class and lesson study group meetings, audio taped interviews (initial and exit), audio taped lesson study conversations, videotaped lessons taught during the methods class, and a final written individual and group report. Only the GRA observed and audio taped the interviews and lesson study group meetings. Of the student written data, the GRA evaluated only the dialogue journals; the instructor evaluated the rest of the data as a regular part of the course.

Data Analysis

The researchers approached the study based on the literature that preservice teachers express confidence in mathematics and yet struggle to explain mathematical ideas conceptually. One participant, Janica, a pseudonym, was a strong student (cumulative GPA of 3.88). She had stated confidence in her mathematical abilities and yet when she taught her first lesson to her peers, could not provide a conceptual explanation of how the signs worked for division of integers. Because the researchers found Janica's mathematics teaching seemingly at odds with her stated beliefs, and thoroughly consistent with the idea that preservice teachers exude mathematics self-confidence and yet can not describe mathematics concepts well, we chose to study her as she participated in lesson study.

The researchers used a general qualitative methodology to analyze the data and develop Janica's case. The GRA utilized initial survey and interview responses to create a preliminary holistic picture of Janica. This initial theory consisted of Janica's confidence level, her beliefs about mathematics and her mathematics knowledge. Subsequent data were analyzed and measured against these initial theories. The lesson study data showed how group members interacted, and how ideas were received and supported by members of the group. The ongoing journal responses gave insight into Janica's inner thoughts. The final interview questioned Janica about her initial comments and followed up on ideas that emerged during the lesson study conversations. Evidence of agreement with or departure from Janica's original ideas was sought, while descriptions pertaining to mathematical ability and the perception of mathematics were of particular interest. An analysis of this final interview supported further refinement of the description of Janica's beliefs and confidence. Recognizing that belief systems are *sensible systems* and in an effort to find coherence between Janica's statements and her actions, the GRA conducted a follow-up interview to address some apparent inconsistencies. The GRA then used the follow-up interview data as a lens to examine all of the previously gathered data and as a member-check to address unresolved issues.

Results

Janica's Background

Janica was a senior mathematics education student with an accomplished school mathematics background. She was conscientious and her pursuit of college mathematics could easily be called a success. She entered college having successfully completed advanced placement BC calculus. In her college coursework up to the time of the study, she had a cumulative GPA of 3.88 and a math GPA of 3.59. Her mathematics coursework included abstract algebra, real analysis and complex analysis (this course was not required for her major). In the semester immediately following this study she successfully completed a graduate course in matrix analysis while still an undergraduate. Her drive to excel came from a time when she received a B+ in an elementary school mathematics class. She remembered thinking that she was not a B+ student and decided never to get anything less than an A again. This powerful event caused Janica to strive for excellence in her subsequent mathematics courses.

About half-way through college, Janica took an 18-month break to engage in missionary work. As a missionary, Janica developed a strong affinity toward teaching. Upon returning home, she enrolled in a private religious university and added education classes to her mathematics schedule. Janica gained employ-

ment with mathematics education professors and began reading articles about educational systems of other countries, transcribing mathematical conversations and working with preservice mathematics teachers. Janica's work experience had briefly introduced her to lesson study, so Janica approached the lesson study experiment with enthusiasm.

Janica reported feeling confident in her secondary mathematics knowledge. In class she consistently referred to conceptual elements in teaching mathematics. However, when she taught her first lesson to her peers, she was asked to explain why a negative number divided by a positive number had a negative quotient. She was unable to do so and left the room in tears at the conclusion of her lesson. Her early journal and interview responses tended to be procedural in nature and indicated some weaknesses in her secondary mathematics understanding. These data seemed inconsistent with Janica's stated confidence in her mathematics knowledge. Janica often *said* conceptual mathematics was important and yet *behaved* as if mathematics was all about procedures. This researcher-viewed inconsistency will be addressed in more detail later.

Janica's view: What is mathematics?

When asked: What is mathematics? Janica reported:

> Mathematics is the study of numbers and the manipulation of numbers… an explorative science that builds from basic concepts to more complex ideas to abstract ideas. The basic building blocks of mathematics are numbers and manipulatives with numbers or symbols representing numbers or functions. Mathematics is used to solve day-to-day… and more universal problems. All sciences use mathematics as a way to represent and manipulate data.

Janica's reply showed she valued mathematics concepts and problem solving and then focused on mathematics as a vehicle of manipulation. The view that procedures are used to solve real-world problems became a common theme for Janica and stemmed from her integrated high school mathematics and physics class.

In the initial interview, Janica contemplated what would be important for students to understand about fractional division. She said "it's hard just off the top of my head; it's easier if I have like a book so that I can see… what students are going to need to know, and apply it." She finally mentioned inverting the fraction and multiplying. When asked to create a problem, she shared an example of "three cups of flour" and wanting "to half the recipe." She eventually realized this was multiplication and not division. She came to this conclusion because if she took three divided by a half, the quantity would be larger, not smaller. When asked to draw a division of fractions problem, Janica shared an example of cutting a five-inch string into half-inch pieces. This model emphasized the concept; however, Janica revealed the source of the model, a textbook. Later, in response to a question to draw a picture of three divided by two-thirds, Janica attempted to use her own model, but finally reverted to the book's string model. When pressed to elaborate, Janica struggled to conceptually describe her drawing. She finally said, "Thanks, this is a good review."

As part of the course, the professor stressed that a critical part of writing lessons was identifying and stating the "big mathematical idea" or BMI. "Early on [Janica] thought everybody was kind of confused…. What exactly [the professor] wanted, what he thought was the big mathematical idea." Also Janica felt that since she did not have the teacher's editions or previous chapters that it was hard to isolate the main idea. "That's one of the problems with the way the class was set up" she said, "a little bit with the text that we got, that, when I was… writing some of my lessons I didn't know what the big mathematical idea should have been." In preparation for teaching a mathematics lesson Janica's BMI for integer division was, "Quotient of 2 integers with the same signs…are positive and quotient of 2 integers with different signs are negative." The mathematical idea she considered most significant centered on rules. Janica's teaching of the lesson followed her BMI closely, and focused on the procedural process of integer division. Partway into the lesson, students questioned why the procedures worked; Janica then struggled to finish the lesson. She realized she was not prepared or flexible enough to handle the students' concerns. Janica later reflected that the "lesson was a flop" and she "assumed that the class knew more" than they did. Later, in the final interview Janica described a typical lesson as presenting the rules and applying them.

Janica's view: Mathematical expert

Janica addressed her confidence in mathematics. In the initial interview, she remembered she learned high school mathematics quickly and helped other students with their lessons. In the final interview she said that the "beginning material is going to be easy because it's always…just background and the foundation material, so of course that will be fine." This confidence influ-

enced her view of her mathematics knowledge.

In light of Janica's confidence in mathematics, Janica supplied a different reaction to teaching mathematics. In response to a final interview question about how she would teach slope, Janica said, "Asking a question like that is sort of…dumb because I don't have a background in teaching up to that point and I don't know exactly what's gunna be after." In the same interview, Janica's response to: "Does it bother you to know that you're…maybe not as complete in your [secondary mathematics] knowledge…?" was the following: "I've forgotten so much that I would have to just…and every teacher does I'm sure when they're starting out to teach a new subject, just having to review the material and really understand what's going on." Also, "I think I'm a little more confident…that even though…I realize I don't know a lot of the mathematics, and I've forgotten a lot, it will come back and I'll be able to teach it." Janica pointed out that even though she lacked teaching experience and had forgotten some mathematics, she agreed that through review she would have the background knowledge needed to teach the subject.

Lesson study

Janica's lesson study group, consisted of herself and three other preservice teachers: Cindy, McKenna and Robin (all pseudonyms). With a high school pre-calculus teacher, the group decided on a learning goal and a mathematics topic for lesson study. The preservice teachers and cooperating teacher decided to focus on justification while teaching logarithms. During the meeting, Janica spoke often, asking questions about how the students comprehended mathematical ideas, the characteristics of the students and the lesson's logistics. Janica later referred to *The Teaching Gap* (Stigler & Hiebert, 1999), and shared her impressions of the development of the lesson study process. She said "knowing a little bit about lesson study…they actually chose like a math topic…talked about it, researched about it, and came up with a lesson to more fully explain it and help the students understand it."

During the first planning meeting another participant, Cindy, kept track of the group's ideas and suggestions in a lesson plan outline. Half-way through this meeting Janica commented that the group needed to write down their ideas. In the second planning meeting, Janica stood at the board and began to write, commenting that she enjoyed writing on the board. This drew the group's attention away from Cindy's outline and from this point on Janica acted as the group's official scribe. Often as discussion ensued, many ideas were lost as Janica tried to make sense of the lesson plan on her own. When Janica did not agree with an idea, instead of writing down the idea, she thought of how she would ask the question and asked for a group consensus.

During collaboration, the preservice teachers shared ideas on the underlying principles of logarithms and exponents. Early on Janica did not speak much but spent her time looking in the textbook for information. At first she was particularly interested in the logarithm tables and the symbolic representation of logarithms. While working to prove the property $\log(ab) = \log a + \log b$, Cindy said "Maybe we don't know how to do this." And McKenna wondered, "So is this ever gunna work?" Janica reached for the book and queried, "Did they develop it anywhere?" Later, she told the group that even after taking the book home that she "didn't read through the [logarithm] chapters very well."

The group continued to work through the proof of: $\log(ab) = \log a + \log b$. Cindy questioned the group about a particular concept of logarithms and exponents asking:

Cindy: Well, can't 'a' be written as 10 or 5 or whatever to some power? That's…what a logarithm is…writing a number as…the base to a power…if we stress that big enough, maybe [the students will] see that they need to write their number as a base to a power.

Janica: The only problem is that it's an arbitrary number, it could be anything. The only reason we choose it, is so we can prove it…We specifically choose an 'a' and a 'b' so that we could show that it works. Otherwise if, we'd…end up with all these decimals if we choose numbers and stuff. But this was a clear way to show that it was true.

Cindy: What do you mean?

Janica: 'a' and 'b' can be anything.

Cindy: Yeah, I know. I just mean, like we need to stress that, that any number can equal a base to a power. So that they can see that 'a' can equal the base to a power, see what I'm saying? I think if we stress that enough they should be able to make the connection. Don't you guys think? Do you think?

Robin & McKenna: Uh-hu.

Janica: What did you mean…any number can be written as a base to a power?

Cindy: Like any number like 200 can or 100 can be written as base 10 to the power of 2.

Janica: Cuz, there's like 2.

Cindy: 2 can be written as base 10 to some decimal

power, see what I'm saying? Well see, what do you mean? 2 where as in, 2 instead of a 100?
Janica: Or pi.
Cindy: Pi?
Janica: Or any irrational number?
Cindy: Can't they?
McKenna: Hmm?
Janica: Nuh-na. (negative intonation)
Cindy: Not all of them?
Janica: I don't think so. Can they? (looks at GRA in room)

This exchange between Cindy and Janica highlighted Janica's level of understanding of the fundamentals of exponents. After hearing Cindy's statement, Janica tried to make sense of the idea but since she had never heard this mathematical idea before, she struggled to determine the statement's validity. Also Cindy was considered to have the least knowledge about logarithms since she had missed studying the subject in high school as a result of her family moving. The discussion ended with Janica's comment, "I've never thought of it as actually a base to a power and that's why, since I've never heard it, that's why I don't know if it would be true or if it is true."

Although much of the discussion during the lesson study conversations centered on understanding mathematics, Janica said that part of the reason the lesson study group struggled to create a lesson plan was because they were "inexperienced preservice teachers" and that "there's only so much [they knew] about pedagogy…about how to present the mathematics to students." In her eyes there was good and bad to the inexperience because the lesson planning process would have moved quicker with a more experienced teacher. However, she felt the inexperience "might be good because that [gave them] sort of a fresh approach on how [to] teach the lesson…" Janica's reference to inexperience meant inexperience in teaching mathematics, not mathematical knowledge.

Follow-up Interview

During the follow-up interview, Janica responded to the interviewer's description of Janica. Janica wholly agreed with three statements, disagreed with five and had a mixed response with the rest. Janica agreed with, "People look up to me because I know mathematics," disagreed with, "Lesson study did not change the way I view my knowledge of mathematics," and reported some agreement and disagreement with, "I never learned the type of mathematics that I know I should teach." With respect to this, Janica reported disagreeing with the idea that she had the knowledge needed to teach, but agreed that she probably learned the mathematics at some point. Overall, the follow-up interview highlighted how Janica still held onto many of her previous ideas about her knowledge but that she was slowly assimilating new ideas about mathematics education.

Near the end of the interview, Janica shared her personal feelings about her mathematics ability. She confided that the first interview task of drawing three divided by two-thirds made her uncomfortable. She was relieved to provide an answer but thought, "What would I have done if I did not have the example from the book to use?" Upon further inquiry, Janica admitted she would have felt "dumb" if she had struggled with the topic. Thankfully, the book's example had saved her some embarrassment.

After the admission of her true feelings, Janica found an NCTM Principles and Standards (2000) passage that summarized her first interview thoughts. Janica identified with the quote because she felt that answering a question speedily confirmed that she was mathematically bright. The passage she shared was: "Many students have developed the faulty belief that all mathematics problems [can] be solved quickly and directly. If they do not immediately know how to solve a problem, they will give up, which supports a view of themselves as incompetent problem solvers" (p. 259). For Janica, this idea of being categorized as not knowing mathematics was very real and came through in a journal entry and a subsequent conversation with the researchers. She wrote in her journal "I begin to feel inferior/superior depending on my level of knowledge and experience with the particular subject." Janica was referring to feeling inferior or superior in relation to her peers depending on how she perceived their mathematics knowledge compared to her knowledge. Thus, part of Janica's self-worth was associated with her mathematical understanding, or lack thereof.

Discussion

Research (Ball, 1990; Borko et al., 1992; Cooney, 1999; Mewborn, 2003) confirms that Janica's confidence in her mathematical knowledge was similar to the confidence held by other preservice teachers. Often future mathematics teachers display "a strong computational orientation" (Cooney, p. 165) or perceive mathematics as "a collection of arbitrary rules to be memorized" (Ball, p. 460). Janica's notion that mathematics consisted of procedures, and her strength in

mathematical computation, sustained her view of herself as one who was good at mathematics. Secondary mathematics majors have "reported their mathematical knowledge as being the one aspect of teaching about which they felt most confident" (Meredith, 1993, p. 331). Because these secondary majors were above average in high school and later majored in the subject, they were confident in their subject matter knowledge (Ball). This confidence is often misplaced because "often preservice teachers have a poor understanding of school mathematics — having last studied it as teenagers with all the immaturity that implies" (Cooney, p. 165). So even though teacher candidates, like Janica, had experienced success in college mathematics and felt that their secondary mathematics knowledge was "fine," this did not signify a thorough understanding. It should be noted, however, that Janica mentioned that the lesson study group's disagreements led them "to understand logs on a more in-depth level" and they "all understood logs much, much, much better than [they] did coming into it." Therefore, Janica acknowledged that lesson study had enriched and deepened her understanding of this particular secondary topic.

The researchers found it difficult to understand Janica's actions because her comments and actions seemed at odds with one another. Janica's statements in class and during interviews supported a conceptual orientation of mathematics; however, Janica's teaching lacked reference to mathematics concepts. Also, throughout the study Janica stated that she felt confident in secondary mathematics, yet her actions indicated an area of weakness. Even after reflecting on a secondary mathematics topic in lesson study, Janica still did not present any evidence to suggest that she acknowledged this weakness. Janica actually gave ample evidence to the contrary, that she was in fact defending her position as a knower of secondary mathematics. The researchers questioned, "Was this intentional or unintentional? Was she trying to keep from addressing her mathematics knowledge? Since Janica's framework of beliefs must be sensible, what was the coherence between her confidence and actions?" The follow-up interview helped the researchers find consistency between her verbal statements and actions.

Janica's reactions during the follow-up interview highlighted the cultural pressure Janica felt to be an expert in the field of secondary mathematics. She felt the cultural expectation that preservice secondary mathematics teachers should know secondary mathematics. Janica did not want to reveal that she lacked the mathematical knowledge necessary to adequately discuss the mathematics problems. She feared being perceived as "dumb" or unintelligent if she could not solve the problems quickly. These fears stemmed from her perceived expectation to be mathematically knowledgeable.

Janica's compensation moves

Like Antonio (Siebert et al., 1998), Janica used moves to conceal a weakness in her understanding of mathematics; however, her motivation was very different than Antonio's. Janica felt that the culture expected her, as a mathematics major, to know mathematics. When Janica failed to meet this expectation, she attempted to hide her weakness through compensation moves.

Move 1: I'll need to review. Janica's first compensation move came in various forms as she sought help from outside sources to review material. In both the initial and final interviews, Janica commented that she would need a book to answer questions about fraction division and slope. In the episode dealing with fraction division Janica even utilized a book's example to address two questions related to division. After struggling to answer the interviewer's questions Janica finally said, "Thanks, this is a good review." In the final interview, Janica expressed the notion that as a new teacher she would have to "review the material and really understand what's going on" because she expected to have forgotten the specific secondary topic. Janica's comment that this was a good review or that she forgot the little details of a topic focused the attention away from her secondary mathematics knowledge. While engaged in lesson study, Janica once again turned to the book for help. During the $\log(ab) = \log a + \log b$ episode, Janica depended on the book to walk her through the proof and commented that she had not read the logarithm section thoroughly enough. Then later she turned to the researcher observer for concept clarification. The fact that Janica turned to outside sources showed she did not trust her own knowledge, and "if [she] could not figure something out, [she] assumed [she was] 'rusty'" (Ball, 1990, p. 464), rather than initially learning a topic. This compensation move was revealed as Janica looked to a book or researcher for help, and emphasized the need for review.

Move 2: Acting as the scribe. The second move was acting as the lesson study group's scribe. Janica took on the role of *acting as the scribe* to help the group manage the lesson's mathematical flow, however, in the

process Janica kept from sharing too much information about her mathematical knowledge. This compensation move allowed her to speak and ask questions of clarification as the scribe, and not speak as Janica trying to clarify her own understanding. Frequently other members of the group admitted that they did not understand an idea and sought the group's help in making sense of the material. Janica, rarely, if ever, made such an admission. Overall the lesson study collaboration session consisted of the group discussing the rich mathematical principles underlying not only logarithms but exponents as well. These rich mathematical discussions helped the participants plan their lesson as well as examine their own individual understandings of the mathematics topic. Consequently, by directing the conversations, Janica regulated how much information the group members had about her mathematics knowledge.

Move 3: Class structure was to blame. The third move was when Janica blamed the class structure for her inability to identify mathematical ideas. The first indicator of this defense was in an interview when Janica blamed the professor for not helping her pinpoint the big mathematical idea of a topic. She thought she had to figure out what the teacher wanted and expressed feelings of confusion when given the assignment of identifying the main idea of a mathematics lesson. Janica blamed this confusion on the teacher rather than on her developing sense of mathematics ideas. Janica also blamed the course materials for her struggles in identifying the main idea of a mathematics topic. Because Janica did not have the book to look to, she blamed the class organization for her inability to solidly identify big mathematics ideas. Since Janica's criticism of the course focused on either the teacher or class textbook, this indicated that in her mind the GRA was not part of the course staff. Thus her moves during the interviews were not done from fear of external evaluation by the GRA but out of an internal concern for how the community viewed her.

Move 4: That's a pedagogical question. Janica's last compensation move was emphasizing that she had trouble because of her lack of pedagogical knowledge. If she thought a question referred more to mathematics teaching, she often said *that's a pedagogical question.* In the initial interview, the interviewer asked Janica to write down everything she would want her students to know about division of fractions. She explained that she needed a book to help her prepare a lesson for students. This dependence on the book was couched in terms of making curricular decisions and focused the attention away from her mathematics knowledge and on her personal knowledge of pedagogy.

Another way Janica hid her lack of knowledge was by explaining that she might not have an answer to questions about educating mathematics students. Since changing to a mathematics education major, Janica felt that ideas about teaching were new to her. In response to a question about how to teach slope, Janica replied that since she did not have experience teaching the subject, she could not answer the question. Even with the sense of confidence that surrounded her mathematical knowledge, Janica freely admitted that she was not as confident when it came to teaching mathematics. When asked how the lesson study collaboration went, Janica replied that the preservice teachers were "inexperienced" and therefore this led to their struggles during lesson planning. Janica did not attribute their struggles to a lack of understanding of the mathematics topic, logarithms, but rather their lack of mathematics teaching knowledge. Like other preservice teachers (Cooney, 1999), Janica saw mathematical and pedagogical knowledge as separate and distinct knowledge bases. Hence, she believed that she lacked the knowledge necessary to make good pedagogical decisions, and her secondary mathematics knowledge did not influence these decisions. Janica utilized this compensation move, of a weakness in pedagogical knowledge, to protect her identity as a knower of mathematics.

Conclusion

Although Janica claimed to be confident in her understanding of secondary mathematics, the data revealed various actions or 'moves' Janica used to unknowingly keep from revealing any weakness in secondary mathematics. In particular, when faced with a supposedly familiar topic, Janica turned to outside sources or said *I'll need to review*, indicating that she thought she knew it at one time but had not practiced it lately. During lesson study, Janica controlled the flow of the conversations and asked clarifying questions *acting as the scribe* rather than as Janica. Also, she felt the *class structure was to blame* for her inability to identify the underlying concepts on the weekly lesson plans. Finally, when Janica was unable to describe the mathematical concept associated with a secondary topic, she excused it away by saying, *that's a pedagogical question.*

Because of the culture's perceived connection between mathematical performance and natural ability

(Stevenson et al., 1990), Janica had come to view herself in a way that suggested any falter in her secondary mathematics performance reflected on her intelligence. As seen in the follow-up interview, she feared being seen as mathematically incompetent in front of her peers and the researchers. With this fear, she utilized natural defense mechanisms to protect her image. Janica had pushed the attention away from her mathematical knowledge and pointed to other aspects of her knowledge she could admit were weak without threatening her self-image.

While it appeared as if there was a conflict between Janica's claims about the strength of her mathematical knowledge and her moves to protect her self-image, the follow-up interview revealed that Janica was insecure about her mathematical knowledge. This admission allows us to see that Janica's beliefs and actions were, in fact, consistent and coherent (Leatham, 2006). During the follow-up interview, Janica admitted she was aware of her lack of secondary mathematics knowledge. She commented that her knowledge of logarithms had grown as she engaged in lesson study collaboration and that lesson study forced her to rethink and redefine her fragmented knowledge of the subject. As a result, Janica was able to openly admit that the topic of logarithms was difficult for her.

Simply put, Janica is a case of a preservice mathematics teacher who had a strong mathematics background as measured by her GPA in university mathematics courses and yet exhibited weaknesses when discussing and presenting lessons about high school mathematics. Because of the culture's pressure on mathematics preservice teachers to know all of the subject matter, Janica exhibited the defense mechanisms compensation moves to protect against being seen as "dumb".

In the Borko et al. (1992) study, Ms. Daniels struggled to explain fundamental mathematics and yet claimed that she was satisfied with her lesson. Is it possible that there were no "contradictions between her beliefs and knowledge" (p. 221) but that she too was using compensation moves to keep from revealing weaknesses in her mathematical knowledge?

We acknowledge that because this is a case study, we only have data that allows us to describe Janica's feelings and actions. However, because the teaching culture was the primary source of Janica's beliefs, we posit that this sentiment is held by many preservice teachers and that this would be fertile ground for future research. The teaching culture leads new teachers to believe that when they have completed their degree they should know all of the subject matter knowledge needed to teach (Stigler & Hiebert, 1999). In some situations passing a standardized tests provides teachers with the sense that they are "highly qualified teachers" (Berry et al., 2004, p. 686). In the case of mathematics, it is believed that a teacher's knowledge of the subject matter is based on their natural ability (Stevenson et al., 1990) and thus closely associated with their personal identity. Hence, discussing mathematics in a way that would reveal any weaknesses is a sign that they are not meeting the culture's expectations. Acknowledging that preservice mathematics teachers will not know all of the mathematics they need to teach secondary mathematics may allow them to be more teachable before they begin teaching and lifelong learners after they start.

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A Case Study of Three Childrens' Original Interpretations of the Moon's Changing Appearance

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A case study of three children was conducted to shed light on the process that children undergo in developing their understanding of physical phenomena. Using the notion of spontaneous construction and its relationship with school learning of scientific concepts, children's early thoughts of the moon's appearance were explored. Research questions were primarily concerned with how children view the moon's appearance, explain how and/or why its appearance changes, quantify the moon's size and its distance to Earth, and explain the moon's illumination. A Piagetian interview was conducted with each child and then each was asked to tell a story about the moon. The external interest of this research study involves when and why do children develop the commonly held Earth's shadow alternative conception as the cause of the moon's phases. The findings show that children have stories and experiences that give meaning to the existence of such things as the moon, stars, sun, and clouds. Similarities were found in the children's interpretations with regard to their natural tendencies to animate celestial objects. Clues were discovered of cultural influence such as family, personal observations and experiences, books, pictures, car travel, and even a strategically placed Palladian window.

Introduction

Narrative, including fictional narrative, gives shape to things in the real world and often bestows on them a title to reality.

Bruner, *Making stories*, 2002

In Bruner's (1986) essay "The Two Modes of Thought", he discussed the two paradigms, narrative and logico-scientific. He explained that although the two paradigms are often interdependent, they function differently, in that, "arguments (logico-scientific) convince one of their truth, stories (narrative constructs) of their lifelikeness" (p.11). Egan (1989) supported the notion that learners are better able to generate authentic thought when both paradigms are integrated. He challenged, "Consider how you learned whatever you consider most valuable. We pick up bits and pieces, and suddenly see connections; these break or defract, and are recomposed in new ways with disparate pieces" (p.13).

Students often come to the classroom with pieces of understanding or preconceived notions about physical and biological occurrences that hold up well with their prior experiences (Chi & Roscoe, 2002; diSessa, 2002; Posner, Strike, Hewson, & Gertzog, 1982). However, these naïve notions are often not scientifically sound in explaining the natural phenomena. Much research has shown that even after instruction, students regularly revert to their alternative understandings (Bransford, Brown, & Cocking, 2000; Libarkin & Kurdziel, 2001; McDermott, 1984; Minstrell, 1992). Piaget (1962) described two different ways in which concepts are understood by children (whether correctly or incorrectly). One is spontaneous, which is influenced by interaction with the social, familial, scholastic, milieu, etc., and the other is that of school learning or the formal transmission by instruction.

> In some cases, what is transmitted by instruction is well assimilated by the child because it represents…an extension of some spontaneous constructions of his own. In such cases, his development is accelerated. But in other cases, the gifts of instruction are presented…in a manner that precludes assimilation because it does not fit in with the child's spontaneous constructions (p. 8 – 9).

Vygotsky (1987) wrote, "The strength of everyday concepts lies in spontaneous, situationally meaningful concrete applications" within the "sphere of experience" (p. 220). Everyday concepts are spontaneously constructed by the young child within their home life surroundings due to their situational, cultural experiences and activities with family and friends. How well these everyday concepts transcend or assimilate to scientifically accurate understandings in the school learning environment is truly determined by the effectiveness of the teacher and his/her ability to honor the child's pre-instructional understandings and create new situated learning experiences which allows adequate *assimilation and accommodation* (Piaget, 1962) with other scientific bodies of knowledge. In other words, children must be given the opportunity to assimilate the information that they know and to adapt

when disequilibrium or conflict occurs as a result of new knowledge gained within the school learning environment. When children's pre-instructional fragments of understanding are recomposed in such a way to bring balance (or equilibrium) is the point at which Piaget claimed assimilation and accommodation had occurred.

Developmental Modes of Thought of Scientific Concepts Concerning the Moon

Using this notion of spontaneous construction and its relationship with school learning of scientific concepts, the author explored children's early thoughts regarding the moon. It was hoped that better understanding would be gained regarding how young children think about the natural world and, in particular, the moon and its appearance and origination. Few research studies have been conducted with *young* children (under the age of nine) in science education due to the many obstacles associated with data collection and analysis. This research study provides educators with meaningful information about young children's understandings of the moon from where educational teaching and research programs can be aptly designed and developed. One of the key ideas behind teaching for conceptual change is that we need to better comprehend and appreciate students' pre-instructional ways of thinking, which is the main achievement of this research.

Numerous research studies conducted with elementary children's understanding of astronomical phenomena showed them having many alternative conceptions (Baxter, 1989; Dunlop, 2000; Schoon, 1992; Stahly, Krockover, & Shepardson, 1999). For example, Baxter described five notions used by children aged 9 – 16 years to account for various astronomical events, such as explaining moon phases. These notions included: a) Clouds covering the moon; b) Planets casting a shadow on the moon; c) The Sun's shadow falls on the moon; d) The Earth's shadow falls on the moon; and e) The correct explanation of the phases due to the portion of illuminated side of the moon visible from Earth (p. 509). Of these many explanations accounting for the moon phases, the predominantly held notion by the children in the Baxter study was that of the Earth's shadow falls on the moon. Schoon conducted a cross age study with 1,213 students. The survey revealed 48.1% of the subjects surveyed to believe that the different phases of the moon are caused by the shadow of the Earth falling on the moon, and an even more interesting finding was that this conception became more popular with age where 69.5% of college level students accepted this notion (p. 210).

Other studies showed similar findings regarding students' alternative conceptions concerning the cause of moon phases (Abell, Martini, & George, 2001; Bisard, Aron, Francek, & Nelson, 1994; Fanetti, 2001; Sadler, 1987; Schoon, 1992). Fanetti claimed that there could be a correlation between students' ignorance of moon size, Earth size, and Earth-moon distance that assists them in holding the Earth's shadow misconception.

These alternative conceptions are not simply reserved for the child, but are also found in the understanding of many in-service and pre-service teachers. Trumper (2001) conducted a study of astronomy misconceptions among students from middle school through university. He found that 16% of the future elementary teachers assessed thought that moon phases were caused by the Earth's shadow, while 29% believed they were caused by the Sun's shadow. Furthermore, their astronomical understanding was lower than that of the middle school students surveyed. Trundle, Atwood, and Christopher (2002) discovered that 46% of the 78 pre-service elementary teachers that participated in their study clung to their common moon phase alternative conceptions held prior to instruction, and none possessed "complete scientific understandings" of this phenomenon. Upon interviewing their participants, Callison and Wright (1993) found that some pre-service elementary teachers believed that the moon and the sun were the same body, with the moon appearing during the night and the sun making its appearance during the day.

Children hold ideas that were developed before and during their early school years, and these ideas may be compounded by the teacher and/or the textbook (Trowbridge & Mintzes, 1985). Sadler (1987), in his attempt to identify the sources of alternative conceptions amongst 14 and 15 year old students regarding the phases of the moon, concluded that the chief culprit was the schooling of the pupils. Skamp (1998) argued that unless the alternative understandings of educators are replaced with scientific explanations, it is unlikely that teachers will be able to help students understand the phenomena. Callison and Wright (1993) summarized,

> If a teacher has a shallow or incomplete understanding of a phenomenon, there is a risk of selecting inappropriate models. Additionally, in an attempt to create useable models, one could miss

the dimensions of a model which could become a source for misconceptions (p.10-11).

Several research studies described young children using a 'blocking' notion, such as clouds covering the moon, to explain why the moon's appearance changes (Acker & Pecker, 1988; Baxter, 1989, 1995; Dunlap, 2000; Sharp, 1996). Haupt (1950) researched first grade children's understanding of what caused the moon to have different shapes. He found 61.9% of the children stated they did not know, 19% claimed cloud coverage, one child reported "the night hides some of the parts", and another said "the north wind is greedy and eats the moon a bite a day and the south wind blows it back" (p. 233). Haupt also found that when asked about the size of the moon, children gave responses of "inches, miles, room, rubber ball, princesse's [sic] thumb nail, desk, circle, star, sky, sun, New Jersey, and United States" (p. 231).

Young children (ages 4-8) do begin to construct their own understanding of the natural world (including the moon) prior to formal schooling and, indeed, are influenced by not only family and friends, but also by children's books, pictures, television shows, movies etc. However, most of this coming to know occurs in fragments or "bits and pieces" (Egan, 1989). If one also factors in that children of this age group are judged to be in Piaget's (1972) preoperational stage, then they are considered to be cognitively egocentric - having tendencies to "lack differentiation between one's own point of view and the other possible ones" (Piaget, 1962, p. 2). Children of stages 2 and 3 (preoperational and concrete, respectively) also display qualities of animism and artificialism. Animism concerns the idea that objects are living, conscious, and endowed with will, whereas artificialism relates to the object being "the product of human creation, rather than in attributing creative activity to the things themselves" (p. 253).

Exactly what factors fuel preoperational children's development of their current and future conceptions of the moon and its phases? When do the conceptual "bits and pieces" take shape, or "break and defract" and then "recompose in new ways"? In the previous section, it was reported that numerous literature citing children's and adults' (including teachers) predominant moon phase alternative conception to be that of the Earth casting a shadow on the moon (from the age of nine through adulthood at an increasing rate as they age). But what about young children, the preoperational children, will they have the shadow alternative conception? Do young children even understand the concept of shadow? According to Sia (1980), "Children at ages 6 to 8 could hardly describe shadows except that they were black in color. The 6-year olds could not form shadows. They could point to the shadows formed but could not explain why they appeared" (p. 7). Feher and Rice (1988) found in interviewing children (ages 8 - 14) that half of the subjects, the younger ones, believed that shadows were out at night. Piaget (as cited in Feher & Rice) "tells us that children 5 to 9 years of age think of a shadow as 'a substance that emanates from the object themselves' and 'travels about.' Very young children (ages 5 and 6) regard this substance as being alive and conscious" (p. 646).

I follow with a research study concerning the cases of three children of the preoperational age group where focus is on their current understanding of the moon and its phases.

Methods

This research involved an instrumental case study of three female children, two were age 6 (Lizbeth and Ellen) and one was age 8 (Robyn). All children lived in the United States (US); two resided in the Northern US and one in the Southern US. Eight-year-old Robyn was adopted at the age of 2 from China. Lizbeth and Ellen had both just finished kindergarten and Robyn had just completed the second grade. No participant knew each other or attended the same school and pseudonyms were used for all children.

According to Stake (1995), participant selection for a case study can be based on concerns other than those relating to a sample of a population. For example, convenience and/or the likelihood of obtaining interesting results can also be the rationale for a case selection. All of the interviewees were chosen because the children's parents were family acquaintances. Robyn was also chosen since she was adopted from China and it was thought that her Chinese background might affect her interview responses. All three children were from families of middle to high social economic status.

In order to ascertain the children's thinking regarding the moon, clinical interviews were conducted by the author, with each audiotaped, videotaped, and transcribed. Interviews with Robyn and Ellen were conducted in their family homes, and Lizbeth's interview was conducted at her aunt's home. Each interview lasted approximately twenty minutes and all of the children's mothers were present during the interview. In order to gather further information concerning the

children's everyday experiences that might assist with better understanding the children's interview responses, the author also conducted interviews with each child's mother after the child's interview. The interviews with the mothers lasted approximately ten minutes. Fathers were not to be excluded, but none were available during the interview time period. All interviews were videotaped and transcribed. Permission to interview, videotape, and photograph was obtained from all participants' guardians.

The interview protocol (see Appendix) was developed by Louisell, Kazemek, and Wellik (2007) while consulting *The Child's Conception of the World* by Piaget (1929). I compared my interviewee responses with some of the interviews conducted with children by Piaget himself to see how responses concerning the moon have changed or remained the same from one century to the next. For example, would children of today include technological references (i.e., television, computers, etc.), or were children of yesteryear more avid sky watchers due to lack of light pollution, no television or video games, etc.?

I also added several questions to the interview protocol that were of particular interest; however, no wording was changed of the original Louisell et al. (2007) question protocol. My external interest involved when and why do children develop an Earth's shadow alternative conception. Stake (2000) would classify this as an instrumental case study where a particular case is analyzed to provide insight into an issue or to redraw a generalization.

> The case is of secondary interest...and it facilitates our understanding of something else. The case still is looked at in depth, its contexts scrutinized, its ordinary activities detailed, but all because this helps the researcher to pursue the external interest (p. 437).

Two researchers were involved with the immediate data collection and analysis of interview responses for Sections I, IV, and V of the interview protocol (Appendix A). However, for Sections II and III, two additional researchers assisted with data analysis. Employing multiple researchers and perspectives allowed for triangulation. Nine interview questions (see Appendix A, section I, questions 6, 7, and 20 – 24, and section V, questions 1 and 2) were added to the interview protocol to help better answer the following research questions.

1. What explanations will young children give regarding the moon's changing appearance?
2. What ideas on the moon's size, illumination, and distance to Earth will young children communicate?
3. How do the children's interview responses regarding the moon conducted by Piaget (1929), nearly a century ago, compare to this current study?

In the analysis of the children's responses, careful attention was paid to possible cultural influences that the children might have experienced that caused them to answer all questions in the manner in which they did. For example, what everyday influences such as books, stories, siblings, adults, friends, television, movies, and environmental factors contributed to the child's vision and understanding of the moon and sky. In depth interviews and interview analysis gives much richer data than that of a multiple choice survey. In these interviews, I had the opportunity to study how children think and explain something that they may never have before considered.

The Louisell et al. (2007) interview protocol also includes a section that adapts Applebee's (1978) research on children's construction of stories (section II of Appendix A). The protocol requests the child to tell a story about the moon. At the conclusion of the child's story, each child is asked if the story they just told really happened. Analysis of the children's stories was conducted using Applebee's structural analysis where he classified children's plot structures into six categories, which are:

a) *Heaps* – The story's organization is rooted in immediate perception with few links from one sentence to another (p. 59);

b) *Sequences* – The story's associations between the incidents and their center are limited to bonds of similarity rather than causality (p. 60);

c) *Primitive Narratives* – The story has an object or event that has temporarily assumed some importance to the child, which is then developed by collecting around it a set of complementary attributes (p. 62);

d) *Unfocused Chains* – The story has incidents that lead directly from one to the other, but the linking attributes continue to shift (p. 64);

e) *Focused Chains* – The story's center or main character goes through a series of linked events, but the main character is rooted in the concrete (p. 65); and

f) *Narratives* – Each incident in the story not only develops out of the previous one, but at the same time elaborates a new aspect of the situation (p. 65).

While categorizing the brief stories told by each of the three cases, special attention was paid to what the story's center was, what role the moon possessed in the

story, and what language was used to describe the moon. Through analysis of the children's moon stories, further light could be shed upon their understanding of the moon and sky.

Data Analysis

The data analysis was organized by grouping the research questions into three categories: a) moon phases noticed by children and why the moon's appearance changes; b) children's ideas on moon size, moon distance, and moon illumination; and c) comparison of children's responses with Piagetian moon interviews. Analysis of the children's lunar stories in section d) was conducted using Applebee's (1978) structural categories. Using Applebee's structural categories to analyze the children's lunar stories was a powerful tool to illustrate similarities and/or differences between each story, and allowed a particularly unique way to focus on each story's center, flow, and introduction of new characters.

a) Moon phases noticed by children and why the moon's appearance changes

Each interview began with asking the children if they ever saw the moon at night and if they could describe it. Ellen reported to have seen the moon look like a blue circle. Lizbeth also first reported to have observed a circular moon, and followed with a description of a waning crescent moon she had viewed. Robyn said she saw the moon by a tree and it looked like a banana, soon after she stated that she had also seen it look like a circle. The following is an excerpt of Robyn's interview.

J: It looked like a banana? Show me how it looked like a banana? Can you show me with your hands? (Robyn cups her left hand into the shape of a C.)

J: Okay, did you ever see the moon look any different than a banana?

R: A circle.

J: So sometimes it looks like a circle? Well how come sometimes it looks like a circle and sometimes it looks like a banana?

R: Because it is a full moon.

J: Oh, and when it is a full moon which way does it look?

R: A circle.

J: A circle? So, but why … why does sometimes it looks like a banana and sometimes it looks like a circle, do you think?

R: Because the sky is hiding part of it?

J: Oh … okay, because the sky is hiding part of it. So, what in the sky is hiding part of the moon? (Robyn is silent and then says she does not know.)

Robyn described two moon phases, that of a waning crescent (her C shaped banana) and that of a full moon (a circle). According to Robyn, the moon's changed appearance was due to the sky hiding part of it. Although this was a blocking response, the "object" blocking the view was the sky, not the commonly held notion of a cloud as described by Baxter (1989).

When interviewing Robyn's mother, she was asked if she could recall any time recently when Robyn talked to her about the moon and sky. She described how they sometimes saw the moon through their front *Palladian* window, which faces east, and how Robyn often became excited when she saw the full moon or a "sliver of a moon" through the window. Robyn's mother also stated that the moon and stars were especially noticed on Halloween, but did not state any particular moon phase noticed on this celebrated day.

Robyn and her mother were both asked if Robyn ever read (or had read to her) any books regarding the moon (whether at home or at school), but neither could recollect having done so. In Robyn's kitchen, wallpaper bordered the kitchen walls at Robyn's eye level that displayed a pattern from left to right of a sun, a waning crescent moon, a full moon, and a cloud. All were shown with animated faces. At the end of the interview (which had been conducted in her living room), Robyn was asked to come into the kitchen and show, again, her "banana" moon. She, like before, displayed this phase making a "C" shape with her left hand. Robyn was asked if this same moon she had observed was shown anywhere on the wallpaper and she proceeded to point to the waning crescent moon on the border.

It is interesting that Robyn reported observing a waning crescent moon (in its "C" orientation). This phase is mainly up during the daytime and would be difficult to notice (a waning crescent rises before dawn and at first would appear as a bowl shape). However, Robyn's mother did state that Robyn sometimes saw the moon, including a "sliver of a moon", through their large, eastward facing *Palladian* window. If she were looking out the window before sunrise, a waning crescent moon could be clearly visible. Another possibility of explaining Robyn's "banana" moon phase is that she was influenced by the kitchen wallpaper that showed a waning crescent moon.

At the end of each interview, all children were shown two pictures, one of a waxing crescent and the other of

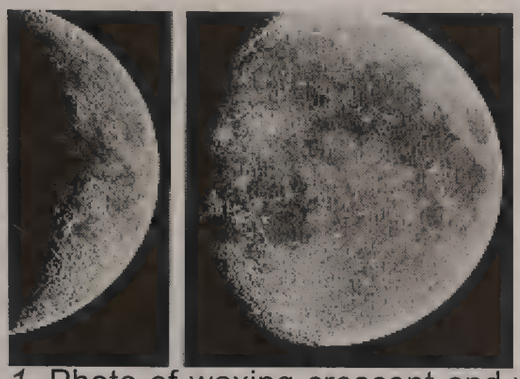

Figure 1. Photo of waxing crescent and waxing gibbous moon (Menzel and Pasachoff, 1983, p. 322).

a waxing gibbous (see Figure 1). When Robyn was asked if she ever saw the moon looking like either of the two pictures, she said she had seen the picture of the waxing gibbous, but never saw the waxing crescent. A waxing crescent moon sets after the sun, and usually is quite spectacular in the evening southwestern sky for those of us in the northern hemisphere. Robyn did not think she had ever seen the waxing crescent moon like the one displayed in Figure 1, but both Ellen and Lizbeth reported having seen one when each of them was shown the picture.

As stated earlier, Ellen first reported having observed a blue moon and also said, later in her interview, having viewed both the waxing crescent and gibbous moons shown in Figure 1. When asked why the moon sometimes appeared differently, she responded, "Because the sky covers it up". So, like Robyn, Ellen had this "blocking" idea accounting for the moon's multiple appearances. This was quite interesting that two of the three interviews in this case study showed children describing the moon's changing appearance to be attributed to the sky covering it up as if the sky were some entity or substance that can blanket a portion of the moon.

At the beginning of Lizbeth's interview, she was asked to describe the moon she had observed when she had been outside.

L: It was a circle. It had these little holes in here.

J: What were these holes? What were they for? You know?

L: Maybe, maybe, maybe, maybe for little things to go in, maybe little pebbles fall on it.

J: Okay. Okay. Well can you tell me anything more about it?

L: I am not very sure.

J: Okay, did you ever see the moon look any different than that?

L: Like this.

(Lizbeth proceeded to draw a large "C" shaped moon in the air.)

Lizbeth, like Robyn, first reported having seen a full moon and a waning crescent moon. When Lizbeth was asked why sometimes the moon looked like the moon she had drawn in the air (the waning crescent) and sometimes it appeared like a circle, she replied, "Maybe it wants to be little…maybe it wants to be half sometimes? Maybe sometimes it wants to be full".

When Lizbeth was shown the pictures in Figure 1 and asked if she recollected having ever seen the moon look like those in the photos, she replied that she had seen both:

J: So why does the moon sometimes look like this (the waxing crescent) and why does it sometimes look like that (the waxing gibbous)?

L: Maybe sometimes it's happy and it looks like the sun (the waxing gibbous), and sometimes it's grumpy and it looks like this (the waxing crescent).

J: So this one is happy when it looks like the sun?

L: Yeah!

J: … and then sometimes it's grumpy and it looks like that?

L: Because when you turn it (the waxing crescent) over it looks like a sad, grumpy face.

Unlike Robyn or Ellen, Lizbeth reported throughout her interview that the moon had a will to change its appearance. These animistic qualities allowed the moon to sometimes be little, sometimes half, and sometimes full. The moon also had feelings that would be visible for all to see, showing its sad and grumpy faces, and at other times, its happy, sunny side.

None of the children in this case study mentioned the word shadow within their interviews. Ellen and Robyn explained that the moon's appearance sometimes looked different due to the sky covering or hiding it, while Lizbeth assumed the moon changed at will. As reported earlier, most young children, when using an object blocking notion, stated that the moon's appearance changed due to cloud coverage (Acker & Pecker, 1988; Baxter, 1989, 1995; Dunlop, 2000; Sharp, 1996). Recall that in the Haupt (1950) study, the majority of the children speculated that the moon's shape change was due to clouds. None gave the moon any animistic qualities; however, one imagined the greedy wind ate the moon. One child said that the night hid parts of the moon, which is a similar notion to that of Ellen's and Robyn's "sky covering".

Table 1
Children's Interview Responses to Lunar Distance, Size, Movement, and Illumination Questions

Questions	Lizbeth (Age 6)	Robyn (Age 8)	Ellen (Age 6)	Haupt's 1950 Interviews
Is the moon close or is it far away?	Far away.	Far away.	Far away.	
Is the sun close or far away?	Far away.	Far away.	Um...	
Well, which one is closer, the sun or the moon? Why do you think that?	The sun to me, I think. Because it's brighter.	The moon. I'm not sure.	The moon. Because I have a friend … um … he lived just two streets and … um … it's closer.	"The moon and the earth move around the sun. They don't bump because they move the same way. It even could be different ways because the moon is close to the sun" (p. 226).
Is the moon ever bright? Well why do you think the moon is sometimes bright?	Yes! Maybe because it took a bath? Maybe it has, maybe it washes itself in a cloud?	Because it, the sky is dark … and it shines.	Because …um … when the sky is dark … um … the moon gets light.	"The sun helps the moon to shine" (p. 227).
How big is the moon?	It's bigger than I can… It's too big I can't make it. It's as big as this room I think.	Um… this big? (Uses her hands to show a span of approximately two feet.)	Um… it's kind of big. Maybe … this big? (Uses two fingers to show a span of approximately two inches.)	"inches, miles, room, rubber ball, princesse's [sic] thumb nail, desk, circle, star, sky, sun, New Jersey, and United States" (p. 226).
Did it look like it was moving? Why?	Actually it isn't moving. You just see it. But I always saw it.	No. I don't know.	Uh-huh. Um … when you're … when you move the car it moves … too.	"I don't know; the moon does not move; a little; if the moon stood still, daylight would never come; if you drive along in a car you can see the moon move" (p. 226).

b) Children's ideas on moon size, moon distance, and moon illumination

When Lizbeth was asked how big the moon is, she stated:

L: It's bigger than I can… It's too big I can't make it.
J: It's too big?
L: It's as big as this room I think.
J: It's as big as this room?
L: I think.

Robyn showed with her hands the moon's size (about 2 feet), and Ellen stated that the moon was "kind of big," and then illustrated with her fingers the size of the moon (about 2 inches). With Ellen, it is unclear if she meant that the moon appears that large in the sky or if she really thought the moon was that big. Table 1 summarizes the children's responses to questions concerning lunar size, distance, and illumination as well as Haupt' s (1950) interview responses. Recall Haupt's study, where children compared the moon's size to that of a rubber ball, a room (like Lizbeth), a thumb nail, and the state of New Jersey (p. 231).

When interviewing about the moon's distance from Earth, the question sequence began with, "Is the moon

close or far away?" The following is an excerpt from Ellen's interview.

J: Is the moon close or far away?
E: Far away.
J: Is the sun close or far away?
E: Um …
J: Which one is closer, the moon or the sun?
E: The moon.
J: How do you know that?
E: Because I have a friend … um … he lived just two streets and … um … it's closer.
J: The moon is closer?
E: Uh-huh.
J: Because your friend lives two streets away?
E: Uh-huh.

Ellen concluded that the moon was far away, but closer than the sun since she viewed the moon over her friend's house who lived two streets away. Robyn thought that both the moon and sun were far away, but the moon was closer to us than the sun; however, she could not communicate why. Lizbeth, like Robyn, considered both the moon and sun to be far away.

J: Well, which one is closer, the sun or the moon?
L: The sun to me, I think.
J: The sun is closer?
L: Uhmm.
J: And why do you think that?
L: Because it's brighter.
J: Okay, the sun is brighter? So, are you saying sometimes the moon is bright?
L: The sun is sometimes bright.
J: The sun is. The sun is bright. Is the moon ever bright?
L: Yes!
J: Okay. Well, why do you think the moon is sometimes bright?
L: Maybe because it took a bath?
J: Oh it took a bath? So sometimes it's bright?
L: Yeah. Maybe it has, maybe it washes itself in a cloud?
J: It washes itself in a cloud?
L: Yes.

Lizbeth put forth a logical argument, explaining that the sun was closer since it was brighter than the moon. When asked if the moon was sometimes bright, Lizbeth exclaimed, "Yes!" and that a possible reason for its brightness was due to its bathing itself in a cloud. Ellen stated that the moon appeared bright at times, "because when the sky gets dark the moon gets light". Similarly, Robyn explained that when the sky becomes dark the moon shines.

In the Haupt (1950) study, children were asked questions in a different manner than this study's interview questions; however, children's responses revealed their thinking about lunar illumination and relative distance between the sun and moon. For example, when Haupt posed the question, "Does the moon move?" one child responded "The moon and earth move around the sun. They don't bump because they move the same way. It could even be different ways because the moon is close to the sun" (p. 226), thus displaying this idea that the moon and sun are relatively near each other (see Table 1). Another Haupt question asked children if the sun had anything to do with the moon? This particular line of questioning led children to respond that "the sun helps the moon to shine" (p. 227), which provided details about the Haupt children's understanding of lunar illumination. None of the children in my study indicated any idea that the moon's illumination was due to the sun. Perhaps because the phrasing of my question was "Is the moon sometimes bright, and (if so) why" did not solicit the consideration of the sun as did Haupt's.

By better understanding how children think about the moon's size, and the moon's distance from Earth and its relative distance to Earth in comparison with the sun's distance, one can better grasp what pieces of understanding children bring to the classroom where their "school learning" begins. This particular question sequence was needed to provide a lens on children's everyday learning and reasoning. The phrasing of the question can also change the children's response as shown in comparing Haupt's interviews with this case study's interviews.

As one can see from this study and the literature, children possess fragments of understanding. The piecing together of these fragments occurs in the formal school environment with teachers, models, and textbooks. However, this is often done with inappropriate models, with incorrect scaling, with textbooks illustrating inaccurate diagrams and representations, and all too often, with teachers who possess many alternative conceptions of their own (Callison & Wright, 1993; Sadler, 1987; Trowbridge & Mintzes, 1985; Trumper, 2001). In order to eliminate the alternative conceptions habitually born in the school learning environment and give children opportunities to correctly assimilate and accommodate their prior knowledge with new knowl-

Table 2
Interview Questions with Animistic and Artificialist Responses

Questions	Lizbeth (Age 6)	Robyn (Age 8)	Ellen (Age 6)	Piaget's 1929 Interwiews
Is the moon alive? How do you know?	I think so. Something in my brain.	Yes. Because … I don't know.	No. Because … it doesn't have any mouth … I mean eyes, nose or mouth.	No…Yes. Because we are alive (p. 259).
How did the moon begin? Any ideas?	Umm, God made it?	I don't know.	Uh … no.	Heaven. It was born from God! (p. 264).
Where does the moon go when you can't see it?	The moon goes down. Ahaaa, um, under somewhere else on the earth?	Oh yeah, when it's raining.	Uh … somewhere else. Maybe to my friend's house.	Perhaps it goes to see the rain in the clouds, or perhaps it's cold (p. 210).
So how come sometimes it (the moon) looks different?	Maybe it wants to be little … maybe it wants to be half sometimes? Maybe sometimes it wants to be full… Maybe sometimes it's happy and it looks like that (waxing gibbous), and sometimes it's grumpy and it looks like this (waxing crescent).	Because it is a full moon. (referring to the circle) Because the sky is hiding part of it? (referring to the banana)	Be … cause … um … the sky… the sky covers it up.	The moon (which sometimes smiled or frowned) reported his misdemeanours to his governess (p. 149).

edge; one must instill in today's educators the importance of being aware of children's early understandings regarding the moon (or any science concepts for that matter). In addition to this, today's educators must also be aware of their own scientific understandings and of the best methods in which to teach them.

c) Comparison of children's responses with Piagetian moon interviews

Similarities were found between the interviews of the three children conducted in this study and the interviews Piaget carried out in the 1920s (see Table 2). Likenesses in animism and artificialism were noted. Recall Piaget's definitions of these two ideas: Animism concerns the idea that objects are alive, whereas artificialism relates to the object as a creation by God or man. Piaget (1929) claimed that, "… before any religious instruction has taken place, artificialist questions are being framed by children of 2 or 3 years old" (p.270), and that the more advanced children are, the less easily they formulate a hypothesis on the origin of the sun and moon. "It is only for the little ones that everything is quite simple" (Piaget, 1929, p. 279).

Lizbeth was the only one of the three that gave an answer to "How did the moon begin?" Her response was not one of strong conviction, but instead sounded more like a question.

J: Okay. How did the moon begin?
L: Umm, God made it?
J: God made the moon?
L: Yes.

Two children that Piaget (1929) questioned regarding the origin of the moon had similar responses to that of Lizbeth. Gaud was a child aged 6 years and Purr was 8 years.

P: How does it [the moon] begin?

Gaud: Quite small; then it keeps on getting bigger.
P: Where does it come from?
Gaud: From Heaven.
P: How does it make itself?
Gaud: Quite tiny.
P: Does it make itself all alone?
Gaud: No, God does it.
P: How?
Gaud: With his hands. (p. 264)
P: Where does it come from?
Purr: From the sky.
P: How did it begin?
Purr: It came from Heaven. It was born from God (!) (p. 264)

When asked if the moon were alive. Both Robyn and Lizbeth thought the moon was alive, but Ellen did not. The following is an excerpt from Ellen's interview regarding whether or not the moon is alive.

J: Is the moon alive?
E: No.
J: How do you know?
E: Because…it doesn't have any mouth…I mean eyes, nose, or mouth.

When asked how she knew the moon is alive, Robyn was unsure and gave no justification for her belief. Lizbeth, on the other hand, said that she was convinced the moon is alive because of "Something in my brain."

J: Something in your brain? So, it is something alive. What else is alive?
L: Plants.
J: Plants. Anything else?
L: People.
J: People? Okay.
L: Flowers.
J: And flowers? Okay. Okay.
L: And dogs and cats and animals.

Roy, a six-year-old whom Piaget interviewed, similarly described his understanding of the moon's animistic character this way:

P: Is the moon alive?
R: No … Yes.
P: Why?
R: Because we are alive (p. 259).

As previously reported, Lizbeth seemed to think the moon willfully altered its appearance according to its happy and grumpy moods (happy when it looked like a sun and grumpy when the crescent moon formed a frown). Consider the following interview Piaget (1929) conducted with Thomas in light of Lizbeth's speculation to why the moon's appearance changes.

> He asked himself with astonishment why the moon appeared regularly. He thought it must have come out just in order to see him. He began to speak to it then and imagined he could see it smile or frown. Finally, he made the discovery that he had been beaten much more often when the moon was visible. It was as if it watched him and reported his misdemeanours to his governess (he was an orphan) (p. 149).

Lizbeth and Thomas described the appearance of the moon as one might describe a stranger. Having somewhat limited knowledge of the stranger, these children could only convey the expressions upon its face to be attributed to its mood. These are two classic examples of animism, as defined by Piaget, where Lizbeth and Thomas attempted to relate to and understand this curious visitor, the moon.

The interview with Robyn revealed her understanding that the moon is sometimes hidden from her view when, and only when, it is raining.

J: Where does the moon go sometimes when you can't see it? Is there a time sometimes when you can't see it?
R: Oh yeah, when it's raining.
J: So sometimes it's raining and you can't see it? Well, is there a time when it's not raining and you can't see the moon?
R: No.

Robyn seemed to believe that the moon remains in the portion of sky visible to her. However, the moon is only blocked from her view whenever a cloud passes between the two of them. Similarly, an interview Piaget (1929) conducted with a four-year old transpired like this:

Later, when the moon was hidden behind a cloud, R (aged 4) said, "Look, now it's been killed." R was told that the moon is not really moving at all and that it only seems as if it is. But three days later she said, "Every now and then the moon disappears; perhaps it goes to see the rain in the clouds, or perhaps it's cold" (p. 210).

This four-year-old girl at first described the moon as "killed" by the cloud that had hidden it. Later, this child proclaimed that the moon "disappears" from time to time. Was this information relayed to her by someone

else in the three days that passed? The animism illustrated in her pondering, "perhaps it goes to see the rain in the clouds," implies that the moon possesses a will to visit the rain as a child might visit a park. Could the child have meant that the moon goes to visit a friend and thereby meant to assign human attributes to both the moon and rain? One can only speculate. Animism was also detected in the child's response, "perhaps it's [the moon's] cold." This seems to imply that the moon may abandon its play due to the cold and return home, wherever that might be. Robyn, unlike the four-year old child interviewed by Piaget, displayed no animism in her response when discussing the moon's non-appearance due to the rain clouds.

In a reply to a similar question concerning where the moon goes when you cannot view it, Lizbeth reported that "the moon goes down…under somewhere else on the Earth". This was quite a scientific response with no evidence of animism, which is curious considering her many previous animistic responses. Recall that she explained the moon's brightness was due, perhaps, to its bathing in the cloud, which seemed to imply that, at times, the moon needed a bath just as she did. It was plausible to her that the rain comes from a cloud and therefore, the cloud would be a suitable place for the moon to wash itself. Both Lizbeth and the four-year-old child, R, of Piaget's (1929) interview hypothesized that sometimes the moon would pay a visit to the clouds. For Lizbeth, the moon was washing itself in the clouds, and for Piaget's R, it was simply to "see" the rain and clouds (thus, causing its view to be hidden).

In her interview, Ellen said the moon was not alive. However, all throughout her interview (including her moon story), Ellen spoke of the moon following either her (moving with her) or her friend, and seeming to possess a will to choose its direction of travel. For example, after she established that the moon followed her, Ellen was asked if she and a friend were walking together and she and her friend separated, walking in opposite directions, "Who would the moon follow?" Ellen stated that the moon would follow her since she was on the right. Either the moon must always follow the person on the "right" or the moon had a preference of following the person on the right. When asked, "Where might the moon go when you cannot see it," Ellen replied, "Somewhere else".

J: So where do you think? What do you mean, somewhere else?

E: Maybe to my friend's house.

In comparing these modern day children's theories regarding the moon's existence with those children of nearly a century ago, many similarities were found. These similarities included both animistic and artificialistic attributes.

d) Children's lunar stories

All children were asked to relate a story about the moon. The stories of Lizbeth, Robyn, and Ellen were classified according to Applebee's (1978) six structural plot categories. Focus was placed on the story's center, the role of the moon, and the language used. Giving children the opportunity to freely weave a story about the moon, allows them to introduce new characters, make connections between the characters, and illustrate creativity with unique lines of reasoning. It was also hoped that it might shed further light upon their original lunar interpretations.

Of the three, Lizbeth's was the longest. Her story began with "Once there was" and ended with "The End", which is similar to the beginnings and endings found in storybooks.

> Once there was a moon that didn't like… Once there was a moon that was all alone. Yes, he didn't want any … he… he wanted a friend. He always wanted a friend, but no one wanted him. So … then he met a friend, a cloud. Then he didn't want him. Then he met a friend … um … um …um a comet and he didn't want to be his friend, so a sun wanted to be his friend so they were friends. They were friends forever. The End.

Her story was classified to be on the border between a focused chain and a narrative. Lizbeth's story's center was the moon that was in search of a friend. The moon went through a series of linked events where 1) he met a cloud, who did not want to be his friend; 2) he met a comet, who also did not wish to be his friend; and 3) he met the sun, who did want to be his friend. Each of these events developed from the previous one, but did not necessarily elaborate an entirely new aspect of the situation, except that the sun and moon were "friends forever".

Lizbeth's characters, the moon, a cloud, a comet, and the sun, give insight to objects in the sky about which she had, either, previously seen, heard, or read. Of the four objects, only the moon and sun were words in the interview protocol. The word "cloud" was earlier mentioned by Lizbeth as she explained the moon's possible bathing habits; however, "comet" was entirely a new term that had not been previously uttered during the in-

terview. Of the four characters in her story, three were masculine, and she did not state whether the sun was masculine, feminine, or otherwise. When asked if the story just told were true, Lizbeth replied, "No. It was fiction".

When interviewing Lizbeth's mother, she stated that Lizbeth was about 4 years old when she began to notice objects in the sky. She described how just the night before the interview, Lizbeth had pointed out "a star all by itself and she commented, 'Look, Mom, at the star!' Then we just said, 'Star light, star bright, first star I see tonight'". Lizbeth's mother also stated that Lizbeth had talked about different planets, such as Mars, and that she had spoken of clouds. "We talked about how they (clouds) changed and they look like marshmallows or different figures".

Lizbeth's mother also commented on a book that Lizbeth loved, *Goodnight, Moon* by Margaret Wise Brown (2006). In this book a picture is shown hanging on a wall of a cow jumping over a waxing crescent moon. The book also accurately illustrates a full moon rising in the evening sky and rises properly throughout the night in accordance with the 10 minute intervals of time shown on the mantle clock.

Robyn's story was the shortest, and like Lizbeth's, had the moon as the story's center.

> Um…there was a moon who didn't like the stars because the stars shine, and so then a star fell and somebody caught it, and then the moon took its place. Um … a person caught the star and then the moon took its place.

Robyn's story was classified as borderline focused chain / narrative. Robyn's main character, the moon, did not like the stars because they shine. Robyn followed with two consecutive incidents that happened to a star, "a star fell," apparently to the Earth, and then "somebody caught it." She clarified this somebody as "a person caught the star", and then the final event that developed from the previous one was that the "moon took its place".

Robyn's main story characters were the moon, the star that fell, and a person that caught the star. She never gave the moon or the star any masculine or feminine attributes. Previously in her interview, she had spoken of stars (other than the sun) as objects she viewed in the sky when she had taken walks at night; and according to Robyn's mother, the moon and stars were especially noticed by the family on Halloween. Robyn, like Lizbeth, stated that her story was made up when she was asked whether or not her story were true.

Finally, we have Ellen's story. Ellen, unlike Robyn or Lizbeth, reported a true story. She continued her pattern displayed throughout her interview of describing how the moon moved either with her or a friend.

> Um … one time I saw a friend … out the window, and uh … I saw it (the moon) moving too… um … I mean … I saw it moving with him and um … he was going to his house. And … um … when he shut the door … um … the moon … he didn't see the moon. And then he went to his room. Um … the moon … uh … then it went to somebody else's house.

Different than Robyn's and Lizbeth's, Ellen's main character was her male friend and not the moon. The moon's role in her story (as best supporting character) seemed similar to that of a dog's role in the numerous stories involving a boy and a dog (i.e., Naylor's 1991 book, "Shiloh"; Hoffman's 2003 story, "Good Boy"), where the story might begin with the dog following a boy to his home. However, Ellen never used the word "following" within her story; she stated, "I saw it (the moon) moving with him". Ellen, herself, was a character/narrator of her story as she reported the true events that she observed from her window.

Ellen's story was classified the same as Robyn's and Lizbeth's, borderline focused chain/narrative. Her story's center, the male friend, went through a series of linked events. He walked home with the moon moving with him. Then the friend went into his house, shut the door, went into his room and was no longer able to view the moon. Ellen's story ends with focus on the story's best supporting character, the moon, going to somebody else's house. Ironically, Ellen, who stated the moon was not alive, seemed to display the moon with animistic characteristics in her true story as she described the moon first moving with her friend, and then traveling to somebody else's house after her friend's door closed (as if it had feelings of rejection and went searching for a new friend).

One wonders what story Ellen might have told if she had not been asked the protocol question concerning whether the moon looked like it was moving. From that point on in her interview, this idea of the moon's moving seemed to take on some significance.

J: Okay, um … did it look like it was moving?

E: Uh-huh.

J: It did? How did that happen?

E: Um … when you're … when you move the car it

moves … too.
J: When you're in the car it moves too? And so, can it follow you?
E: Uh-huh.
J: Okay. Why does it do that?
E: Um … I don't know.

Throughout all of the interviews, Ellen was the only child to mention any kind of technology (car travel) as she described her lunar experiences. As shown in the previous passage, Ellen described her view and "movement" of the moon as she observed it through the window of a car. Ellen, like Robyn's Palladian window, recalled lunar moments framed within the picture window of her family car as well as the window of her family home as she observed the moon "moving" with her friend to his house and then exit to another house after her friend "shut the door".

When interviewing Ellen's mother, she stated that she had no recollection of any books that Ellen might have read concerning the moon and sky. However, at this point in the interview, Ellen explained that she had read a book in kindergarten about the moon.

J: Oh yeah? Do you remember the name of it?
E: Uh … Zoom, Zoom, Zoom, I Am Off to the Moon.
J: Zoom, Zoom, Zoom, I Am Off to the Moon! What's that one about?
E: It's about this kid who was flying to the moon and he was acting like he was in space.
J: Uh-huh?
E: And he had this big … uh… um … space … um … uh … suit on, and at … yeah … but …and, uh… he put on a buckle and he acted like he was in a spaceship.
J: Oh yeah? So did he get to go to the moon?
E: Uh-huh.

Zoom! Zoom! Zoom! I'm Off to the Moon, 2002, was written by Dan Yaccarino. In this story, a boy becomes an astronaut and rides a spaceship to the moon, lands on its surface, collects rocks, and drives a land rover. He returns to Earth with much celebration.

All children's stories were classified as borderline chain/narrative with only Ellen reporting a true story. The moon was the main character in Robyn's and Lizbeth's story, whereas Ellen's main character was her friend. Only Lizbeth reported a new astronomical object, a comet, which had not been previously mentioned during the interview. Without the lunar story component, one would not have found the similarities and differences within each child's narration of linked astronomical events, nor would one have observed the interesting ways in which Ellen observed the moon through her framed window giving the moon animistic characteristics for the first time in her interview. I claim that it was the power of the story that allowed this new lens into the children's mind, which is a method that could be used in productive ways by any educator.

Discussion

> Many scientific…hypotheses start their lives as little stories or metaphors, but they reach their scientific maturity by a process of conversion into verifiability…There is a heartlessness to logic: one goes where one's premises and conclusions and observations take one…Scientists, perhaps because they rely on familiar stories to fill in the gaps of their knowledge, have a harder time in practice. But their salvation is to wash the stories away when causes can be substituted for them (Bruner, 1986, p. 12-13).

With reflection on Bruner's essay "Two Modes of Thought", one might contemplate this idea that scientific hypotheses often originate from stories and reach scientific maturity when they become verifiable. The children in these interviews have stories and everyday cultural experiences (family outings, home décor, children's books, and home windows) that give meaning to the existence of such things as the moon, the stars, the sun, and the clouds. And until different stories are told or more experiences are accumulated, their personal stories will remain, explaining various physical occurrences, albeit with some possible gaps. These valuable accounts that children are sure to bring to the academic environment must never be disregarded as they may certainly be "recomposed in new ways with disparate pieces" as Egan (1989) insisted. Similarities were found in the children's stories concerning the moon, similarities among stories spun by the three children interviewed as well as between these three contemporary accounts and those related by the children Piaget interviewed nearly a century ago. When referring to stories here, I do not simply mean the children's lunar narratives told at the end of their interviews, but the interviews in their entirety. Likenesses emerged with regard to children's natural tendencies to animate and give lifelike qualities to the moon and other celestial objects. It was found, with these three cases, that

the children's understanding of the moon had been influenced by family, personal observations and experiences, books, pictures, traveling by car, and even strategically placed windows. However, no clues were found concerning the influence of technology (other than traveling by car) on the children's lunar knowledge, which was something I considered, might differentiate Piaget's interviews from this current day study. A follow-up study involving larger numbers of young children with mixed gender could shed further light on this matter.

What happens when scientific concepts (such as those concerning the moon and its phases) are confined to academia and are appropriated in relation to other concepts within a system of knowledge? Is this why students who are learning (within a formal school setting) about the cause of the moon's phases begin to appropriate the Earth's shadow misconception because it is often taught in conjunction with other concepts in the knowledge system such as lunar eclipses? Or perhaps, as the child moves "*through* understanding rather than to understanding," he/she is simply moving towards what is thought appropriate for that community (Rogoff, 1998, p. 690). Those of us, who have procured the task of guiding children *through* understanding their universe, must take great care in the manner in which we facilitate understanding so that we do not haphazardly leave them with faulty notions or set up new ones.

As shown within the analysis, none of the three interviews revealed the children having any ideas of moon phases being caused by a shadow (whether it is the Earth's shadow or the Sun's shadow). Two children believed the sky hid part of the moon at times, and one claimed the moon's appearance changed at will. This study also offers new insight into how children think about the size of the moon as they quantified its size with their hands and arms, or compared it to the size of their living room. All believed the moon to be far away from the Earth, which must conflict with some of the inappropriate scale models used within the classroom that display the moon to be relatively close to the Earth.

Implications and Contributions

It is important to realize that this study was not at all about what children within the preoperational stage might be lacking as Fleer and Robbins (2003) suggest is often the case within some early childhood science education writings. Instead, this study highlights the 'openness', 'richness', and 'complexity' of young children's original interpretations, thoughts, and conceptions (Fleer & Robbins, p. 412). By better understanding how children think about why the moon's appearance changes, and how far away and how large the moon is; and also knowing that children have a natural tendency to assign animistic attributes to the moon, one can see what children bring to the classroom where their "school learning" begins. By realizing that this is where their reconstruction occurs, the capable teacher must know the student and create a learning environment—*by design*—that incorporates opportunities for students to move through their understanding with appropriate models and innovative resources. "With deliberate and explicit instruction…the learner must take what were initially bits of knowledge with no clear structure or power and come to see them as part of a larger, more meaningful, and more useful system" (Wiggins & McTighe, 2005, p. 43).

This research provides educators with meaningful qualitative information about young children's understandings of the moon from where educational teaching and research programs can be appropriately developed. One of the main ideas behind teaching for conceptual change is that we need to understand students' pre-instructional ways of thinking and this is the main achievement of this research. Very little research is conducted with young children in science education because of the difficulties associated with data collection and analysis. The adapted Piagetian interview protocol will be made available to other researchers interested in similar research with other children.

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Appendix A

Appendix A: Interview about the Moon

Protocol developed by Drs. Bob Louisell, Frank Kazemek, Jerry Wellik, & Barb Beniek while consulting *The Child's Conception of the World* by Jean Piaget. Questions added by Dr. Jennifer Wilhelm - Section I, questions 6, 7, and 20 – 24, and Section V, questions 1 and 2

I. Protocol to be used in Piagetian clinical interview fashion; i.e. asking follow-up questions based on what the child tells you, but anticipating these topics.

1. [After introductions which include questions about the child's name and age] Have you ever been for a walk outside at night?

2. [If "no" to question above] Have you ever been for a drive at night?

3. [If "yes" to either question above] Where was the moon? [If no specific response is given] Was the moon in the sky?

4. Can you tell me anything about it?

5. [If no response to above question] Did you notice anything about it?

6. What did it look like?

7. [If child speaks of moon looking different at different times.] Why does it look different at different times?

8. [If "no" to question above] Did it look like it was moving?

9. How does that happen?

10. Can it follow you?

11. [If "yes"] Why does it do that? [Or, if "no"] Why not?

12. Has anyone else talked to you about these things? [If "yes"] What did they say about it?

13. [If child says that the moon can follow you] Can it follow two people at the same time? [If "yes"] What if you went this way [point one direction] and I went that way [point the opposite direction]. Which one of us would it follow?

14. Is the moon alive? How do you know?

15. Is there more than one moon?

16. [If "no" to 11, above] Why not? [Or, if "yes"] Tell me more about that!

17. [If "yes" to above] How many moons are there? How do you know?

18. How did the moon begin? Do you have any ideas?

19. Where does the moon go when you can't see it?

20. Is the moon close or far away?

21. Is the sun close or far away?

22. Which do you think is closer? Why do you think that?

23. How big is the moon?

24. Why does the moon sometimes look bright?

II. (To shed light on the child's ability to cognitively distinguish between fact and fiction/fantasy)

1. Can you tell me a story about the moon? (Alternates: Do you know any stories about the moon? Could you make up a story about the moon?)

2. (Alternate to #1, above) Using pictures or picture storybooks that show the moon from different perspectives/viewpoints, show the pictures to the child and ask the questions in #1, above.

III. (To shed light on the child's ability to cognitively distinguish between fact and fiction/fantasy)

1. That story you just told me… Did it really happen? (Alternate: Is it what really happens?)

2. What really does happen?

3. How do you know?

IV. (Also to shed light on the child's ability to cognitively distinguish between fact and fiction/fantasy)

1. When I first started to ask you questions today, and you answered them for me, did you tell me what really happens?

2. (If "yes") How do you know it really does happen? Where did you learn this? (If "no") What really

does happen?

V. (To better understand what the child thinks concerning why the moon's appearance changes.) Children are given two photos, one is a waxing crescent and the other is a waxing gibbous (see Figure 1).

1. Have you ever seen the moon look like either of these pictures?

2. [If yes, and child indicates that the moon sometimes has different appearances.] So, why does the moon sometimes look different at different times? How does that happen?

Appendix B
Protocol for Moon Interview with Parents

Developed by Drs. Bob Louisell, Frank Kazemek, Jerry Wellik, & Barb Beniek while consulting *The Child's Conception of the World* by Jean Piaget

After interviewing the child, show the parent(s) the videotaped interview and interview questions. Ask parents to volunteer any insights they might have about the child's experiences that may have influenced his or her ideas. Specifically, include questions such as:

1. Can you recall any time recently when s(he) talked about this with you?
2. About when (How old was he or she) when s(he) started to talk about these things?
3. Have you shared any experiences together in which you discussed related topics?
4. Have you discussed *other* science-related topics together?
5. What books have you read to your child that relate to this topic?
6. [Questions about religious or "head honcho" influences] Does s(he) go to Sunday School? (Temple? Mosque? Hindu?)
7. Do you read religious literature (e.g. Bible, Koran, Talmud, etc.) to them? Do you discuss religious ideas with them?
8. Has your child recently expressed ideas that reflect who s(he) thinks is most powerful? (e.g. God, Allah, grandfather, father, grandmother, mother, the first people, etc.)

Understanding of Earth and Space Science Concepts: Strategies for Concept-Building in Elementary Teacher Preparation

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This research is concerned with preservice teacher understanding of six earth and space science concepts that are often taught in elementary school: the reason for seasons, phases of the moon, why the wind blows, the rock cycle, soil formation, and earthquakes. Specifically, this study examines the effect of readings, hands-on learning stations, and concept mapping in improving conceptual understanding. Undergraduates in two sections of a science methods course (N=52) completed an open-ended survey, giving explanations about the above concepts three times: as a pretest and twice as posttests after various instructional interventions. The answers, scored with a three point rubric, indicated that the preservice teachers initially had many misconceptions (alternative conceptions). A two way ANOVA with repeated measures analysis (pretest/posttest) demonstrated that readings and learning stations are both successful in building preservice teacher's understanding and that benefits from the hands-on learning stations approached statistical significance. Concept mapping had an additive effect in building understanding, as evident on the second posttest. The findings suggest useful strategies for university science instructors to use in clarifying science concepts while modeling activities teachers can use in their own classrooms.

It is in elementary school that many of the basic concepts about earth and space science are introduced. The research shows that not only students but also preservice teachers (Trumper, 2001; Trundle, Atwood, & Christopher, 2002) and inservice elementary school teachers (Bulunuz & Jarrett, 2006) have many misconceptions in this area. In the *National Science Education Standards* [NSES] (National Research Council, 1996), teachers' misconceptions are highlighted as a serious problem. Elementary school teachers need to have expertise to teach the entire science curriculum including biology, chemistry, physics, and earth and space science concepts at different grade levels. If teachers are expected to teach these concepts, they must have both scientific understanding of these concepts and knowledge of how to teach these concepts effectively to the students (Trundle, 1999). Teachers who don't know they have misconceptions may pass their nonscientific information on to their students. Teachers who feel insecure in their knowledge of the concepts may assign readings from textbooks rather than teach effectively.

This research is concerned with teacher understanding of six earth and space science concepts that are often taught in elementary school: the reason for seasons, phases of the moon, why the wind blows, the rock cycle, soil formation, and earthquakes. Although there is disagreement between the *National Science Education Standards* (National Research Council, 1996) and the *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS], 1993) on when these concepts should be taught, the recently developed *Georgia Performance Standards* [GPS] (Georgia Department of Education, 2006) include all six concepts in the elementary school curriculum. Table 1 indicates when these concepts should be taught according to the NSES, the Benchmarks, and the GPS.

Students come to class with ideas about the natural world. It may be difficult for people, children and adults, to understand scientific phenomena, including earth and space science concepts, because these concepts are difficult to visualize (Callison & Wright, 1993). Prior knowledge of individuals might be correct, partially correct, or incorrect with misconceptions. Many researchers state that misconceptions play a crucial role in learning by interfering with scientific understanding (Hewson, 1981; Trundle, 1999) since individuals with misconceptions may have difficulty learning new concepts because their initial nonscientific understandings interfere with their new learning.

Table 1
Recommended Grade Levels for Teaching Six Earth Science Concepts

	Reasons for Seasons	Phases of the Moon	Why the Wind Blows	Rock Cycle	Soil Formation	Earthquakes
NSES	5-8	K-5	K-4	5-8	K-4	5-8
Benchmarks	5-8	K-5	3-5	9	6-8	9-12
GPS	4	4	4-5	3-5	3	5

Middle and high school teachers generally teach specialized content. However, elementary school teachers need to have a very broad range of scientific knowledge to teach their students. There is evidence that preservice (Atwood & Atwood, 1996; Dai & Capie, 1990; Stofflett, 1994; Trumper, 2001) and inservice teachers (Kikas, 2004; King, 2000) hold the same misconceptions as their students about earth and space science concepts. Various studies investigate understandings about reasons for seasons, with the most common misconception among preservice elementary teachers being "distance theory." Distance theory is described as: when part of the earth is closer to the sun, it gets hotter; and when part of earth is farther from the sun, it gets colder (Atwood & Atwood). Other incorrect explanations for the reasons for seasons identified by Atwood and Atwood include "the rotation of the earth on its axis," "the way the earth is positioned on its axis" and "the part facing the sun is having summer" (p. 557). Parker and Heywood (1998), in a study of inservice teachers, found that *wobbly earth* was another main alternative conception. They defined *wobbly earth* as "the oscillation of earth's axis in summer and winter" (p. 510).

Research on conceptual understanding of the phases of the moon has been conducted with both preservice and inservice teachers. Parker and Heywood (1998) found that most teachers think that the earth's or other planets' shadow onto the moon causes the moon phases. Trundle et al. (2002) reported that many preservice teachers think that the moon phases are caused by the earth's shadow on the moon (eclipse) and the earth's rotation on its axis. In research on preservice teachers (Callison & Wright, 1993) the most common misconceptions on the cause of the phases of the moon were the earth's shadow, the clouds, and the Earth's and moon's tilts.

Misconceptions about rock formation are very common among teachers (Kusnick, 2002; Stofflett, 1994). According to Kusnick, some of the preservice teachers' ideas were that rounded pebbles or rocks found near the rivers must be sedimentary rocks and that rocks are formed by sediments sticking together at the bottom of rivers. The rock cycle is a concept about which both preservice and inservice teachers tend to hold either incomplete or incorrect understanding. Bulunuz and Jarrett (2006) noted that most teachers, when asked about the rock cycle, either left the answer blank or said they did not know.

Libarkin, Anderson, Dahl, Beilfuss, and Boone (2005) investigated the conceptual understanding of college students about the causes of earthquakes and found that some of the causes mentioned were: gas pressure, gravity, the rotation of the earth, exploding soil, expansion of the Earth, and volcanoes. According to King (2000), plate tectonics is taught to children at the ages of 11-14 in geography courses as a factual model. If college students have not taken geology courses, they may rely on facts they tried to memorize but did not understand in middle school.

According to Aron, Francek, Nelson, and Bisard (1994), preservice teachers hold some incorrect understandings about atmospheric phenomena like "why the wind blows." Their study of high school students and preservice teachers found lack of understanding concerning atmospheric processes and phenomena at all age levels, with preservice teachers being very similar to high school students.

Preservice teachers tend to confuse the concepts underpinning "weathering" and "erosion" related to soil formation processes (Hutchinson, 2002). Dove (1999) believes that the reason for confusion is that both processes are concerned with the lowering of the land surface and operate over a long time period. According to Dove, students often believe weathering is a pre-requisite of erosion; however, they do not think these processes operate together and are dependent on each other. This makes these processes and soil formation difficult for people to understand.

Parker and Heywood (2000) argue that since elementary teachers often take few science courses, especially in earth science, one purpose of teacher education must be concerned with helping teachers develop correct understanding about scientific concepts.

Research findings (Dahl, Anderson, & Libarkin, 2005) show that misconceptions are highly resistant to change. Researchers have implemented and assessed various strategies to change naïve ideas of preservice and inservice teachers on various science concepts. For example, studies have evaluated the effectiveness of strategies such as hands-on activities (Haury & Rillero, 1994), concept mapping activities (Kim, Germann, & Patton, 1998), and conceptual change texts (Cakir, Uzuntiryaki, & Geban, 2002).

Using hands-on activities for conceptual change in science has become very popular in the last four decades. To correct students' alternative conceptions, a number of studies have explored the effects of hands-on activities and science experiments on college students (Colburn & Henriques, 2000; Niaz, 2002), preservice teachers (Gibson, Bernhard, Kropf, Ramirez, & Van Strat, 2001; Kelly, 2000; Plourde & Klemm, 2004), and inservice teachers (Bulunuz & Jarrett, 2006; Parker & Heywood, 2000).

The following studies, using various outcome measures, indicate the effectiveness of hands-on activities. In an introductory physical science course for preservice teachers, Gibson et al. (2001) analyzed the effectiveness of constructivist methods including hands-on activities, cooperative group work, manipulatives, and real life applications, on scientific understanding. Analysis of weekly reflective journals suggested that the course had a positive impact on scientific understanding. Parker and Heywood (2000), using sequential floating and sinking activities with in-service teachers, concluded that exploration with various materials engaged the teachers with difficult and abstract scientific ideas and helped them to learn about learning. McConnell, Steer, and Owens (2003) compared the conceptual understanding of college students in traditional versus inquiry-based earth science classes where students were active and collaborative while engaged in hands-on activities. Their interviews of the students show that most of the participants enjoyed the inquiry-based class, preferred the hands-on activities to a traditional lecture class, and would recommend this course to their peers. Ebert and Elliot (2002) found hands-on activities successful in teaching preservice teachers about rock and mineral identification. Gutierrez, Coulter, and Goodwin (2002) concluded that a summer workshop on earthquakes, volcanoes, floods, hurricanes, and tornadoes for elementary school teachers improved teacher understanding. Hands-on learning stations significantly increased the conceptual understanding of new teachers on reason for seasons, the rock cycle, and earthquakes (Bulunuz & Jarrett, 2006).

One way to structure hands-on activities is through centers or learning stations. Although the terms interest centers (Jones, 1999), science centers (Irwin, Nucci, & Beckett, 2003), and science discovery centers (Radeloff, 2001) are used interchangeably in the literature, the term hands-on learning station (Bulunuz & Jarrett) is used throughout this study. In this approach, students work together as active learners, consistent with the National Science Education Standards (National Research Council, 1996).

Increasingly, concept maps are used in a number of settings from elementary school to university, with college students (Gonzalez, 1997; Van Zele, Lenaertz, & Wierne, 2004), preservice teachers (Kim et al., 1998), and inservice teachers (Cakir & Crawford, 2001). Concept mapping is an effective technique for teaching earth science concepts according to Ault (1985), Gonzalez, and McConnell et al. (2003). Ault explains concept map preparation steps on earth science concepts and gives examples of concept maps about igneous rocks, fossils, and precipitation drawn by students in introductory geology and earth science courses.

Investigating Spanish university students' conceptual understanding of a geology topic (silicates) in a two-year longitudinal study, Gonzalez (1997) trained students in concept mapping techniques. By analyzing the students' pre and post concept maps, Gonzalez found that the mapping technique proved an efficient tool in understanding the cognitive structures of college students and in showing the evolution of their knowledge.

In combining concept mapping with other strategies, Sungur, Tekkaya, and Geban, (2001), Cakir et al. (2002), and Tekkaya (2003) investigated the effectiveness of both concept maps and conceptual change texts on Turkish high school students' biological concepts and reported positive effects of concept maps in changing alternative conceptions on biological concepts. Gabel (2003) argues that concept mapping, though sometimes a boring exercise for children, can be effective when used with other teaching techniques.

If teachers think they understand the concepts they are expected to teach, they may not engage in special preparation when preparing their lessons. If they recognize that they do not understand the concepts, they may read about them in books or on-line. However, science methods classes preparing elementary school teachers can model ways for teachers to effectively learn about difficult concepts while teaching them effective ways

to teach these concepts to children.

The purpose of this research was to determine which methods, readings, hands-on learning stations, and concept mapping, were effective in clarifying misconceptions that pre-service teachers may hold. Specifically, this research was designed to answer the following questions:

1. Are hands-on learning stations more effective than readings in clarifying earth science concepts as measured by rubric scores?

2. Does concept mapping improve rubric scores? Is the effect different for concepts taught through learning station activities and concepts taught through reading text?

Method

Participants

Participants in this study were 53 undergraduate early childhood education students in two sections of an inquiry science methods course at a southeastern U.S. urban university. The students were second semester juniors, placed two days a week in first grade classrooms the first half of the semester and second or third grade classrooms the second half of the semester. The data were collected during Spring 2006. The course instructors were the researcher (first author) and another doctoral student in the same department.

Instructional Interventions

In this study, three instructional methods were implemented with the preservice teachers. They were: (a) textbook reading assignments, (b) hands-on learning stations, and (c) concept mapping.

After a pretest, in which students answered open-ended survey questions on the six concepts, students in the two sections were assigned three concepts to read about in a text designed for teachers and three concepts to learn about through hands-on learning stations. The assignments of the concepts were made using a counterbalanced design, with the difficulty of the concepts (evaluated in a pilot study) evenly distributed between the two learning methods. Table 2 shows which concepts were taught by the two methods to the two sections of the course.

Textbook reading assignments. The researcher selected reading assignments from the textbook, *Science K-8: An Integrated Approach* by Victor and Kellough (2004). These readings were selected because they all come from a science methods book specifically written to clarify concepts for teachers. They represent the type of reading a teacher might do when preparing to teach these concepts. After the pretest, the researcher gave reading assignments to each cohort for the three concepts they were to learn through textbook reading. Participants read the assigned articles as homework and came to the next class meeting prepared to list in their dialogue journals the "big ideas" related to the articles. In class, the researcher told the class to write about the big ideas on one specific concept as a random check on whether the students had done the assigned readings. Then, the researcher re-administered the three questions from the open-ended survey concerning the concepts covered in the reading assignments.

Hands-on learning stations. In both undergraduate cohorts, the researcher set up six stations with one or two activities each at tables around the classroom. The activities at these stations focused on the three concepts taught to that cohort through hands-on activities. Approximately four or five students were assigned to each station. The participants in Cohort 1 rotated through stations on *the rock cycle*, *reasons for the wind*, and *causes of earthquakes*. The participants in Cohort 2 rotated through stations on *phases of the moon*, *reasons for seasons*, and *soil formation*. The station activities were adapted from various science activity books and geology lab courses. Before participants rotated through the stations, the researcher presented general

Table 2
Topics Learned by Two Methods: Hands-on Activities and Textbook Reading

	Undergraduate Program	
	Cohort 1 (n = 24)	Cohort 2 (n = 28)
Hands-on Learning Stations on the Three Topics: Activities/Small Group Discussion	1. Rock Cycle 2. Reasons for Wind 3. Earthquakes	1. Phases of the Moon 2. Reasons for Seasons 3. Soil Formations
Reading Assingment: Learning through Reading from a Textbook	4. Phases of the Moon 5. Reasons for Seasons 6. Soil Formation	4. Rock Cycle 5. Reasons for Wind 6. Earthquakes

Table 3
Concept Mapping Assignments According to Mapping Team

Concept Mapping Team	Concept Originally Covered by Learning Stations	Concept Originally Covered by Reading Text
Cohort 1		
1	Rock Cycle	Phases of the Moon
2	Rock Cycle	Reason for Seasons
3	Rock Cycle	Soil Formation
4	Reason for Wind	Phases of the Moon
5	Reason for Wind	Reason for Seasons
6	Reason for Wind	Soil Formation
7	Earthquakes	Phases of the Moon
8	Earthquakes	Reason for Seasons
9	Earthquakes	Soil Formation
Cohort 2		
10	Phases of the Moon	Rock Cycle
11	Reason for Seasons	Rock Cycle
12	Soil Formation	Rock Cycle
13	Phases of the Moon	Reason for Wind
14	Reason for Seasons	Reason for Wind
15	Soil Formation	Reason for Wind
16	Phases of the Moon	Earthquakes
17	Reason for Seasons	Earthquakes
18	Soil Formation	Earthquakes

instructions for working in the stations. At the stations, students read the instructions sheets and collaborated on completing the hands-on earth and space science activities. See the Appendix for instructions given at the learning stations.

Concept maps. The week after participating in the station activities, the first author instructed both undergraduate cohorts about concept mapping by using the familiar concept *water*. She talked about what a concept map is, why concept maps are effective tools in science education, how to draw concept maps, and how to score concept maps for use as an assessment tool. After the groups finished their concept maps about water, they scored their concept maps by using the scoring criteria of Novak and Gowin[1] (1984) and discussed with classmates different ways of drawing concept maps.

Following the instructional session, the researcher randomly assigned participants in each class to nine teams with two or three participants in each. Each team was randomly assigned to draw a concept map of one concept the team members learned about through stations and one concept they read about in their textbook reading assignments. There were nine teams in each cohort, representing all the possible combinations of a concept they learned from readings and a concept they learned from the station activities. Table 3 shows the composition of the nine teams from each class in terms of how they originally learned about the concepts they were to map. Their means on the concepts they did not map served as a comparison.

During the concept mapping activity, participants received manila file folders for drawing their concept maps. Post-it notes enabled them to try different configurations of their concept maps on the folders. After the groups finalized their concept maps with post-it notes, they drew their maps on the folders and submitted them to the instructor before the class ended. The instructor graded the concept maps and gave feedback to the students before the final posttest. Figure 1 is a concept map about *earthquakes* showing full understanding and scored as 3.

Figure 1. One group's concept map of earthquakes.

Data Sources and Data Collection

The data source was an open-ended survey about six earth and space science concepts administered three times: once as a pretest and twice as posttests (once after the textbook reading assignments versus hands-on learning stations intervention and once after the concept mapping intervention). The open-ended survey included the following questions:

"How well do you understand science concepts?"

Try writing simple explanations for the following:

1. Why do we have seasons?
2. Why do we see phases of the moon?
3. Explain the rock cycle.
4. How is soil formed?
5. Why does the wind blow?
6. What causes earthquakes?

The survey was administered in each class either by the researcher or by the other course instructor. The questions were adapted from a survey used by the second author as a teaching tool in her classes. The students spent approximately 10-15 minutes answering the questions. The preservice teachers' answers were scored on a rubric according to level of understanding for each phenomenon. The assignments, interventions, and data collection were conducted as a normal part of the course.

Scoring Rubric

A three-point rubric was created for each of the six concepts. All of the answers were scored as follows: *1* - incorrect answer, *2* - partially correct or answer without full explanations, and *3* - full explanation. Two independent judges calculated inter-rater reliabilities for the six concepts. The reliability coefficients were: (a) reasons for seasons, 0.86; (b) phases of the moon, 0.85; (c) the rock cycle, 0.89; (d) soil formation, 0.95, (e) reason for the wind, 0.88; and (f) earthquakes, 0.72.

Examples from participants' answers to several questions illustrate the criteria for scoring. The following answer on the reasons for seasons was scored as *1* because of the misconception that is called *distance theory*: "The seasons change because we are closer to and farther from it." The following answer about phases of the moon was scored as *2* because the response mentions a correct partial explanation but does not include a full explanation: "Because of the rotation [sic] of the moon around the earth, the alignment of the sun and the moon." An example of an answer on soil formation was scored as *3* because the response mentions that soil is formed from both organic and inorganic materials: "Soil is formed from crushed rock, animal manure (decomposed), earthworms, and grass". Following would be considered complete answers on the other concepts. Rarely was there an answer that was as complete as the following, but answers were scored as a 3 if a basic understanding was shown and no misconceptions were included.

Reason for seasons. The tilt of the earth's axis as it revolves around the sun causes the number of hours of

Table 4
Pretest and Posttest 1 Means and Standard Deviations of The Students' Rubric Scores for Concepts Learned Through Readings and Concepts Learned Through Learning Stations

	Pretest			First Posttest		
Learning Method	*N*	Mean	*SD*	*N*	Mean	*SD*
Learning Stations	47	1.55	.38	47	2.39	.34
Readings	47	1.48	.33	47	2.18	.31

Table 5
Posttest 2 Means and Standard Deviations of the Students' Rubric Scores for Concept-Mapped and Non-cConcept Mapped Concepts Learned through Readings and Through Learning Stations

Condition	*N*	Mean	*SD*	Condition	*N*	Mean	*SD*
Learning Stations but No Concept Maps	51	2.13	.48	Learning Stations and Concept Maps	51	2.45	.61
Readings but No Concept Maps	51	2.10	.39	Readings and Concept Maps	51	2.37	.56

sunlight and the angle of sunlight on various parts of earth to change, with areas of direct sunlight warmer than areas with less direct sunlight.

Phases of the moon. The moon is reflected sunlight, and the orbit of the moon around the earth varies the part of the moon's reflected light that is visible from earth.

Rock cycle. Rocks are of three types (igneous, sedimentary, and metamorphic) categorized according to how they are formed. Various earth's processes change one type of rock to another.

Reason for wind. Surface winds are caused by differences in air pressure (hot air is lighter and rises). Air moves from high pressure to low pressure. Global winds are also deflected due to earth's rotation.

Earthquakes. The earth is made up of tectonic plates that can move because the partly fluid area under the earth's outer crust. The plates colliding and rubbing against each other along a fault line creates pressure that causes earthquakes when released.

Results

To answer question one, concerning whether hands-on learning stations were more effective than readings in clarifying earth science concepts, a two way ANOVA with repeated measures (time x learning method) was computed using SPSS. The repeated dependent variable was the mean of the rubric scores on the concepts taught under the two conditions (reading versus learning stations) and at the two times (pre-post). Differences were found on time, $F(1, 46) = 214$, $p < .001$ and instructional intervention, $F(1, 46) = 8.74$, $p < .005$. Students increased their rubric scores from pre to post and were higher (both pre and post) on topics covered by stations than by readings. However, interactions, that would have indicated higher posttest scores on concepts taught by stations, only approached significance, $F(1, 46) = 3.10$, $p = .085$. Table 4 presents the means and standard deviations of the two conditions.

Question two had two parts: Does concept mapping improve rubric scores? Is the effect different for concepts taught through learning station activities and concepts taught through reading text? To answer both questions rubric scores on the third administration of the survey (second posttest) were analyzed by SPSS using a repeated measures ANOVA. The dependent variable was calculated as follows:

1. Score on concept learned through learning station and concept mapping,
2. Score on concept learned through reading and concept mapping,
3. Average of the scores for the two concepts learned through learning stations with no concept mapping, and
4. Average of the scores of the two concepts learned through reading and no concept mapping.

The two repeated measures were (a) whether or not

concept mapping had been done on the concept and (b) whether or not the concept had been taught through learning stations or through readings. The students scored higher on the concepts for which they drew concept maps, $F(1,50) = 17.71$, $p < .001$, but there were no differences according to whether they had originally learned about the concept by reading or by learning stations, $F(1,50) = .616$, $p > .05$ and no interactions, $F(1, 50) = .105$, $p > .05$. Table 5 shows the means and standard deviations according to condition. A visual comparison between Tables 5 and 4 shows that without concept mapping, rubric scores decreased slightly while with concept mapping, rubric scores increased slightly.

Discussion

This research had several strengths that establish confidence in the findings. Inter-rater reliability of the rubric scores was at an acceptable level. A counterbalanced design was used so that preservice teachers in the two sections of the course had a chance to learn three concepts through readings and three concepts through hands-on learning stations. The concepts taught by textbook reading versus learning stations were purposely distributed between the two cohorts so that the mean difficulty levels of the groups of concepts, as determined by a pilot study, were similar. The science textbook that was selected for the reading assignments was clear and comprehensive on all six concepts and did not bias the study against the reading condition. Also, the researchers chose more than one activity per concept for the learning stations, giving a better chance for the preservice teachers to understand difficult earth science concepts. Because the first author taught about conceptual change and implemented the interventions with both cohorts, this study is strong on internal validity. Unique to this study was the use of group concept mapping as an independent variable, allowing for statistical analysis of the effectiveness of concept mapping as an instructional strategy. One lesson learned from this research is how complex some of the concepts are and how hard it is to create clear models. Recent reading of webpages[2] about the effect of earth's rotation on the wind raises questions about whether the model and explanation oversimplified the effect of the rotation on earth's atmosphere.

The low pretest scores on the six earth science concepts suggests that science methods course instructors should not assume that their students understand basic concepts they will be required to teach in elementary school. To prevent misconceptions from being taught to elementary school children, there is value in providing conceptual change experiences in science methods courses or at least in introducing students to strategies they can use to teach themselves concepts they might not understand.

In this study, hands-on activities were beneficial in helping to clarify concepts. This finding is consistent with previous research showing benefits of hands-on experiences for preservice and inservice teachers (Bulunuz & Jarrett, 2006; Ebert & Elliot, 2002; Gutierrez et al., 2002; McConnell et al., 2003; Plourde & Klemm, 2004). The findings from the current study confirm those reported by Jones (1999) and Irwin et al. (2003) that learning stations with hands-on inquiry activities are engaging and can be helpful in building conceptual understandings.

What was not expected was that the preservice teachers' rubric scores increased almost as much when they learned the concepts through readings from the science textbook. Perhaps this is not surprising since reading textbooks is a typical way for college students to learn. After taking the first posttest, one preservice teacher talked to the researcher about how well he could understand when he read about concepts from textbooks. Some of the concepts in this study may have been particularly appropriate for learning about through readings. Unlike concepts like float and sink that can involve true experimentation (Parker & Heywood, 2000), most of the concepts covered in this study involved either models or explanations. However, the advantage of learning stations over readings approached significance, suggesting that further research is warranted.

A previous study (Bulunuz & Jarrett, 2006) on four earth and space science concepts as well as the current study show that it is very difficult to teach complex concept with just a few activities in a short period of time. In addition, developing the most appropriate models especially about the space science concepts of reasons for seasons and phases of the moon that are complex, abstract and difficult to learn is extremely hard for teachers and instructors. Further research should use other activities and models not used in this study for the concepts that were not understood clearly and should also examine the results of combining hands-on activities with readings.

It was expected that the preservice teachers would show greater understanding of concepts they had mapped because concept mapping had an additive ef-

fect on their understanding. Indeed, the concepts that were mapped received slightly higher rubric scores on the second posttest. However, an examination of the means on the first and second posttests showed that the statistical differences on the second posttest were probably due to a small increase in scores on the concept that were mapped and a small decrease in the scores on the concepts that had not been mapped. In addition to having a small additive effect, concept mapping may have prevented the forgetting of material taught through the readings and learning stations. Concept mapping may have been particularly helpful because it was a group activity. Collaboration among group members helps participants scaffold (Vygotsky, 1978) their knowledge on a particular concept by explaining to one another, asking various questions, and discussing different versions of concept maps they draw. For example, in this study, the participants asked one another about earth science terminology, linking words, and examples that they used in their concept maps. They brainstormed together to come up with the most complete concept maps for their groups. Because of the opportunities for scaffolding, group concept mapping seems to be an appropriate instructional method both for adults and for young children (Fellows, 1993). Further research is needed to separate the effects of concept mapping and group collaboration.

This research suggests that readings, hands-on activities, and concept mapping are all effective in helping to clarify concepts for preservice teachers. Although in this study, any advantages of the hands-on learning stations were marginal, hands-on activities have an added advantage of modeling ways that teachers can effectively help young children develop scientifically based conceptual understanding. The preservice teachers left the course with ideas for hands-on activities and concept mapping that they can take directly into the classroom after certification. What strategies do they employ when teaching such concepts to their students? More research is needed on the carry-over effect of modeling activities in methods classes (e.g., hands-on learning stations and concept mapping) that may be more effective with young children than reading from textbooks.

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Authors' Notes

[1]According to Novak and Gowin's scoring system, *relationships, hierarchy*, *cross links*, and *examples* are the four criteria to be scored. Points are given on these criteria, if they are valid and meaningful. To calculate the total points of a concept map score, one needs to multiply the number of relationships by *one*, the number of hierarchical levels by *five*, the number of cross links by *ten*, and the number of examples by *one.* Then the scores are added. If a concept map had a misconception, invalid expressions, or meaningless links, they were not considered as points.

[2] For a clear explanation see: http://www.physlink.com/Education/AskExperts/ae687.cfm

Appendix

Instructions for Participants to Follow at the Learning Stations

Instructions of the Stations for Cohort 1

Rock Cycle

Station 1. Crayon Rock Cycle

Using the pencil sharpener, shave three crayons into the center of an Aluminum (Al) foil square. Record what it looks like.

1. Fold Al foil to a packet and add pressure by standing on it. Open packet, remove a bit of *stuff,* and tape it onto handout as sedimentary rock.

2. Place packet on the hot plate. Leave until crayons just begin to melt. Take foil from heat with a tweezers, remove a bit of *stuff* and tape to handout as metamorphic rock.

3. Return packet to hot plate and leave until crayon is completely melted. Observe quickly before "magma" cools. After crayon has completely cooled, tape to handout as igneous rock.

Station 2. Rock Classification

You will see different types of rocks and related books about them at this station. These rocks are examples of sedimentary, metamorphic, and igneous rocks. By using the materials, try to understand;

– How these three types of rocks form in nature?

– What is the relationship between these rocks?

Find the names of these rocks by using the books.

Reasons for the Wind

Station 3. a. Movement of Air from a Balloon

1. Take a balloon. Inflate it gently and pinch the mouth of the balloon. How many times did have to blow to inflate it? Think about the air compressed inside the balloon and air molecules outside the balloon? Which has more pressure, the air in the balloon or the air in the room?

2. What will happen if you slightly "unpinch" the balloon's mouth? Try it, aiming the opening toward yourself. Which direction does the air move? What makes the air move from the balloon? What does this have to do with wind?

Hint: Air always travels from the areas that have high pressure to the areas that have low pressure.

b. Inflated Bags

At this station, you will see two plastic bags connected with a tube. One of the bags was inflated before they were connected. If these materials just sit there, what would

happen to them after a while? What will happen if the air in the bag is put under pressure? Lightly press on the bag and observe what happens. Try to explain what happens.

Hint: Air always travels from the areas that have high pressure to the areas that have low pressure.

Station 4. a. Sinking of Icy-Water

Liquids behave like gases (because they are both fluids). We can provide a model of "why the wind blows" by using water. You will use blue icy water and warm water to illustrate how fluids of different temperatures interact. Put some warm water into the graduated cylinder. By using the dropper, add a squirt of blue icy-water to the warm water.Observe how cold water and the warm water interact. Cold air and warm air interact the same way. Think about why and write in your journal.

b. Prevailing Winds

At this station, you will spin a water globe on a home-made lazy susan and watch what happens to the blue fluid when you stop it. The liquid has a pearly material in it (such as in shampoo) that allows flow to be made visible. Did the fluid stop when the globe stopped turning? What direction does the fluid move? Does it flow toward the poles or away from the poles?

If the Earth did not rotate on its axis, the movement of the air over the Earth (wind) would be simpler. But, the Earth is rotating counter clockwise on its axis and the solid earth and the fluid that surrounds it (atmosphere) moves differently* causing global winds (prevailing winds) around the Earth. Would it take longer to fly toward

the east or toward the west?

▪ You can note this difference by spinning a hard boiled egg (solid) and a raw egg (thick liquid). The hard boiled egg spins much faster than the raw egg.

Causes of Earthquakes

Station 5. Earthquake Model

When you come to the station:

1. Hook the spring scale to the bungee cord.
2. Ratchet the cord until taut.
3. Each of you should predict how many clicks of the ratchet it will take to move the bricks (cause an earthquake).
4. Check to see how many pounds of tension there are on the scale when the earthquake occurs and measure how far the bricks move.
5. Does this information help you to predict how many clicks until the next earthquake?

[In a real earthquake, pressure builds up because the plates forming the earth's crust can't move smoothly against one another. Friction keeps them from moving smoothly.]

When you are finished, brush off the brick and the sander belt to remove any loose sand. Also pull out the cord for the next person by lifting both metal pieces away from the cogs.

Station 6. Plate Movements

Use the graham crackers on a paper plate as models of the movement of earth's plates. Draw in your journals.

1. Sliding plates: Slowly slide the two graham cracker halves past each other with their edges scraping against each other in opposite directions.
2. Divergent plates: Slowly pull the two cracker halves away from each other.
3. Convergent plates and subduction: Move the two cracker halves toward each other so that they slowly collide. Carefully, slide the crackers toward each other until they meet. Make the right cracker slowly dive under the left cracker (subduction).

Sliding plates and convergent plates with subduction cause earthquakes.

Instructions of the Stations for Cohort 2

Reasons for Seasons

Station 1. Modeling Reasons for Seasons by Using Styrofoam Balls and Flash Light

Figure A: Use a Styrofoam ball with a pencil through it as the axis and a mark around the center as the equator. Find north on the compass and position the ball on a table so that the pencil eraser is tipped slightly from the vertical and pointed toward the north. Place the flashlight about 15 cm from the opposite side of the ball and observe where the light strikes the ball. Keeping the eraser tipped toward the north, move the ball around the flashlight and turn the flashlight around so it continues to shine on the ball. What do you observe?

Figure B: Shine the light directly at the paper and draw around the light spot (area A_1). Place the paper at slant and again draw around the light spot (A_2). How are these two activities [Figures A & B] connected?

Station 2. Using People as Models for Reasons for Seasons

At this station, one person will be the sun and the others will represent the earth.

1. The "sun" will stand at the center.
2. Decide which direction is north. (Either real north or pretend a part of the room is north)
3. The "earth" people will form a circle around the sun, leaning forward, all pointing their heads the same direction. Heads represent the North Pole; leaning represents the tilt of the earth's axis.
4. The "earth" people revolve counter clockwise around the sun while continuing to lean north. It is very awkward but you can do it!
5. As the earth travels around the sun, determine which season in North America the earth represents in each position.

Station 3. How Warm is Slanted vs. Direct Sunlight?

1. Read the temperatures on the two thermometers to make sure they read the same.
2. Then prop up one thermometer in its black case at an angle in the light beam. It will get slanted light. Prop

up the other thermometer with some books so the light strikes on it directly. The bulbs of the thermometers should be the same distance from the light, 15 cm.

3. Wait five minutes (you can read books), then record the temperatures. Are they the same? If not, why not?
4. Remove the thermometers to prepare for the next group.

Phases of the Moon

Station 4. Phases of the Moon

Model 1: Look in the black box. The lamp represents the Sun, the bigger ball with the flag represents the earth and the small ball represents the moon. Place the earth in the cup a bit toward a corner of the box so that its axis (stick) points away from the sun.

- One person will hold the moon by its stick and, keeping the "face" of the moon toward the earth, revolve the moon around the earth in a counter clockwise direction, slightly above the earth so the earth does not block the moon.
- Looking down on the earth, imagine how much of the moon you can see every 90°. Notice how the lighted part of the Moon seems to change shape, from a thin line, or crescent, to a full moon then begins to get smaller and smaller until you have no reflected light.
- Rotate the earth counterclockwise on its axis so you can see whether the moon is visible day or night. Can you see a full moon during the day? Why or why not?

Model 2: Because the researcher and the science faculty member could finalize the second model in the last minute, there was not an instruction sheet for that model. The researcher made the necessary explanations for the preservice teachers.

Soil Formation

Station 5. Soil formation:

You will find two different types of soil (dirt) at this station. One is from near a creek and one is soil from a garden. By using magnifying glasses and microscope, look at these two soil samples, and sort what is in them. What types of bits and pieces do you see in them? Can you find any creatures? Try to find out what the soil made of. What differences do you find between the two soil samples?

Station 6. Rocks in soil

Sometimes pieces of rock are found in soil. One kind of rock (feldspar), weathers chemically and becomes clay. Sometimes rock weathers (wind and/or water) and becomes sand. Sand can be made from many kinds of rock but most of the common sand is quartz. Particles that are larger than clay and smaller then sand are called silt. Make some sand by putting some small rocks in the can and shaking it. You can experiment with the dry can or the wet can. After you have shaken it for five, minutes feel in the bottom of the can to see whether it feels gritty. Remove a bit of grit and examine with a magnifier.

Using Metaphors as a Tool for Examining Preservice Elementary Teachers' Beliefs About Mathematics Teaching and Learning

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This study used metaphors as a tool to gain insight about preservice teachers' conceptualizations of the role of the teacher and the learner and held the view that the examination of these metaphors might provide an opportunity for teacher educators to reflectively and critically examine those beliefs. Thus, this research examined possible differences in the reflected beliefs of elementary preservice teachers as depicted in their metaphors about mathematics teaching and learning at three different points throughout their mathematics education methods courses. The results of this study indicated that elementary preservice teachers' beliefs primarily remained static throughout their mathematics methods courses despite ongoing experiences designed to challenge and extend those beliefs.

For more than a century John Dewey has encouraged the development of reflective thinking in educators. He argued that an important goal of teacher education programs should be to promote critical reflection in preservice teachers regarding the problems and complexities of teaching (Dewey, 1965). Dewey (1933) defined reflective thinking as an "active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it, and further conclusions to which it tends ..." (p. 9). He contended that educators who are not actively involved in inquiry and reflective thinking about the problems in education and the problems with the practice of teaching may be more likely to defer to and to depend on those individual theories that provide precise instructions on how to teach (Dewey, 1965).

Mewborn (1999) identified three conceptualizations of reflection evident in current literature stating that, "[f]irst, regardless of the definition of reflection that is employed, reflection is qualitatively different from recollection or rationalization. The component of reflection that distinguishes it is the problematic nature of the object of thought" (p. 317).

Secondly, she noted that action is an essential part of the reflective process. Reflection and action must be inextricably connected to constitute reflective thinking. Lastly, she stated that a "...common theme in the literature is that reflection is both an individual and a shared experience. Reflection involves a great deal of introspection, but it also requires some outside prompting and probing, at least in the early stages" (Mewborn, 1999, p. 317). In order to develop the kind of persistent, active, reflective thinking in preservice teachers that Dewey (1933) contended is the primary purpose for teacher education programs, teacher educators must provide opportunities for preservice teachers to examine their beliefs. These opportunities should involve preservice teachers in more than mere recollection of what they have been taught but rather experiences in which their beliefs are questioned and ideas probed; experiences that foster introspection.

Despite ongoing efforts for change in mathematics education (National Council of Teachers of Mathematics [NCTM], 1989; 2000), research suggested that preservice teachers' beliefs about teaching and learning remain constant throughout their teacher preparation with most beginning teachers entering classrooms employing traditional pedagogical approaches to teaching (Kagan, 1992; Kilpatrick & Stanic, 1995; Treagust, Duit, & Fraser, 1996). This resistance to change may be due to the fact that preservice teachers typically enter teacher education programs with preconceived notions about mathematics teaching based on numerous years of experience as mathematics learners in classes with

teachers whose dominate pedagogic practices are traditional and teacher centered (Bramald, Hardman, & Leat, 1995; Carter & Doyle, 1995). If experiences in teacher education programs are to bring about meaningful transformation for preservice teachers, teacher educators must provide opportunities for students to critically examine their own thinking and beliefs about teaching and learning. Tobin and LaMaster (1992) believe that because metahors can be used to conceptualize particular teaching roles which may guide the practices adopted by teachers, metaphors can provide an important focus for reflection in teacher education programs. Duffy, Gipe, and Richards (1992) also state that, "researchers interested in alternative ways to evaluate teacher's cognitions suggest that beginning professionals' metaphors may also indirectly reveal their beliefs and orientations about teaching" (p. 3). If preservice teachers' metaphors can reveal their conceptualizaltions about teaching and learning, then the examination of these metaphors may provide preservice teachers, and teacher educators alike, a way of knowing and a way to reflectively and critically examine those beliefs (Moser, 2000; Slingerland, 2004).

Researchers have used metaphors as a tool for examining and reflecting on teacher beliefs and metaphorical analysis has been used to examine preservice teachers metaphors for school (Mahlios & Maxson, 1995), reflective writings on diversity (Parsons, Brown, & Worley, 2004) and autobiographies to examine teacher development (Berci, 2007). Shaw, Barry, and Mahlios (2008) pointed out the need for research using metaphors as a tool for examining content specific beliefs and used metaphors as a tool to examine lietracy beliefs of preservice teachers while Zapata and Lacorte (2007) used metaphorical analysis to examine beliefs of preservice and inservice foreign language teachers beliefs about teaching and learning. This study adds to this research base by using metaphorical anaylsis to examine preservice elementary teachers content specific beliefs about teaching and learning mathematics.

This study adopted the view that metaphors provide insight about preservice teachers' conceptualizations about the role of the teacher and the learner and that the examination of these metaphors may provide an opportunity for teacher educators to reflectively and critically examine those beliefs (Gibbs, 1992; Lakoff & Johnson, 1980). Thus, the purpose of this study was to examine possible differences in the reflected beliefs of elementary preservice teachers as depicted in their metaphors about mathematics teaching and learning at three different points during their mathematics education methods courses. The specific research question guiding this study was: Do preservice elementary teachers' beliefs about mathematics teaching and learning vary at different points in their mathematics methods preparation?

Based on Kliebard's work, Schubert (1986) identified three root metaphors for education including production, journey, and growth metaphors. The production metaphor is an industrial model that envisions the student as raw material to be transformed by a skilled technician who uses rigorously planned specifications, avoids waste, and carefully sees to it that the raw materials are used for the purposes that best fit them. This metaphor aligns with the common portayal of education as a factory and students as its product. The teacher is central and in total control, serving as the "giver" of all knowledge while the students are passive learners working independently to master isolated skills with an assumption of sameness for all.

In the journey metaphor, the teacher serves as a tour guide who leads students through a terrain rich in knowledge, skills, ideas, appreciations, and attitudes. The tour guide knows that each traveler will respond differently to the trip because of his or her unique configuration of background, ability, interests, and purposes. Within this metaphor the teacher is portrayed as a facilitator of knowledge supplying needed tools while the students are active participants who are excepted to respond differently and are allowed to work collaboratively assuming that each student may develop something slightly unique.

The growth metaphor portrays the teacher as a nuturer akin to an "insightful gardener" who carefully learns and understands the the unique character of his/her plants (students) and and works to foster their own special kind of flowering. Students in this metaphor are viewed as active participants whose talents and abilites are developing and growing. Curricular decisions are based on student interest and are continuallly evolving through conversation between and among the students and teacher with collaboration as an accepted social norm in the classroom.

Methods of Inquiry

Participants and setting

Table 1
Participant Demographics

Time	Gender	Ethnicity	Major
No math methods N = 73	7 males 66 females	86% Caucasian 7% Native American 1.4% African American	20% Early Childhood 80% Elementary
1 math method N = 85	1 male 84 females	77% Caucasian 13% Native American 2.2% African American	18% Early Childhood 82% Elementary
2 math methods N = 42	1 male 41 females	91% Caucasian 2% Native American 2% African American	100% Elementary

This study involved 200 preservice elementary and early childhood teachers in a teacher education program at a large Midwestern public university. Data for this study were collected at three different points in this teacher education program; prior to the first mathematics methods course (N=73), following the first mathematics methods course (N=85), and finally following the last mathematics methods course (N=42). Participants were predominately Caucasian females (see Table 1). The first mathematics methods course was required for all preservice elementary and early childhood majors focusing on mathematics pedagogy at the K-3 level. Since the second methods course had a focus on grades 4-8 mathematics pedagogy, only preservice elementary education majors were enrolled in this course. Ages of the participants ranged from 20 to 48 years old with all but eleven participants reporting an age less than 25 years old.

Both of these mathematics methods courses used NCTM's (2000) *Principles and Standards for School Mathematics* as an organizational structure. Additionally, NCTM's (1995) definition of assessment suggests that students' should be assessed on their content and procedural knowledge, process skills, and mathematical dispositions. Thus, both content and process standards were central to curricular activities and learners mathematical dispositions were highlighted at various times in both courses. Additionally, in each of the two mathematics methods courses, constructivism as a theory of learning was central to all components of these courses. In course activities, teacher educators provided many opportunities for preservice teachers to compare and contrast the role of both the teacher and the learners in a traditional classroom setting with that of a more student-centered standards-based setting. Students were involved in a variety of activities that were designed to promote reflective thinking (Dewey, 1933). For example, during the first week of the second mathematics methods course, students were required to write a mathematical autobiography where they reflected on their own positive/negative mathematical experiences, mathematical dispositions (likes/dislikes, feelings, emotions, confidence, etc.), beliefs about how people learn mathematics, and how they perceived an "ideal" teacher of mathematics would view learning mathematics.

Data Collection

To control for consistency in the data collection process one researcher explained the concept of metaphor and collected data from all three groups of participants. Prior to data collection, the concept of metaphor was discussed with participants. The definition of metaphor as "a figure of speech in which a word or phrase literally denoting one kind of object or idea is used in place of another to suggest likeness or analogy between them" (Merriam-Webster, 1995) was presented to the participants. Likewise, a metaphor was further explained as a form of comparison that directly compares two unlike things. The following examples were provided for participants to consider in order for them make sense of the concept of metaphor: "Susan is a doll"; "I am drowning in money"; "When you say about your friend 'He's as grumpy as a bear today,' you do not mean that he is growing bushy black fur. Rather, you mean he is in a bad mood and ready to attack like a bear might be." Following this explanation participants were supplied with a blank sheet of paper along with markers and colored pencils. They were then asked to determine a statement "mathematics is … [blank]," construct a visual metaphor for mathematics teaching and learning, and describe their metaphor in writing making sure to include both the role of the

Table 2
Framework for Metaphor Analysis

Role of...	Production	Journey	Growth
Teachers	Total control; Giver of knowledge; Authoritarian; Teacher-centered	Tour guide; Keeps track of progress; Gives tools	Nurturing; Caring; Listener
Students	Raw material; Passive learners	Active participants; Respond differently	Active learners; Gain empowerment; Talents grow
Curriculum	Isolated; Basic skills; Same for all	Framework; Somewhat integrated	Completely integrated; Driven by student interest; Open and emergent (evolving)
Environment	Departmental; Quiet; Independent work	Cooperative	Interactive; Collaborative; Engaging; Continually evolving

teacher and the role of the learner.

Data Analysis

A table of categorization (see Table 2) based on Kliebard's work which identifies three metaphors for learning and curriculum, production, journey, and growth (Schubert, 1986), was developed by the research team for use in analyzing the data. The research team selected three random metaphors to analyze together for data analysis training in order to ensure consistency for the independent phase of the analysis process. Following team data analysis training, each metaphor was analyzed independently by each member of the research team. Once independent data analysis was complete the findings were compared for inconsistencies and the research team worked collectively to reconcile any inconsistencies. A 100% agreement about each metaphor was reached among the members of the research team.

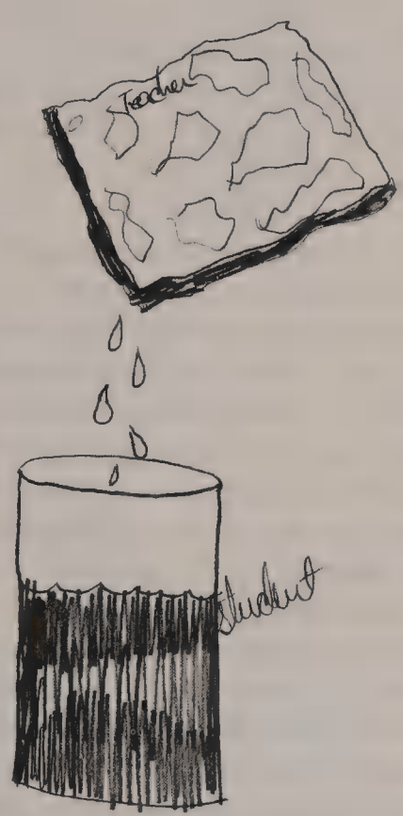

Figure 1. Sample production metaphor.

Findings

Based on the results of categorizing the preservice teachers' metaphors, the production metaphor was overwhelmingly the most common metaphor drawn with between 48% and 62% of each group expressing a metaphor that depicted a production metaphor (see Table 3). Typical production metaphors included *Mathematics is ....a sponge and water* (see Figure 1), ... *a box of tools*, ... *a surgical procedure*, and ... *a cornerstone – foundation*. Metaphors categorized as production indicated in some specific way either pictorially or in writing that students passively receive knowledge from teachers. For example, in Figure 1 the student depicted the teacher as a sponge full of knowledge, squeezing it out into the empty glass (student).

The categorization of the preservice teacher's metaphors further revealed that between 10% and 19% of each group constructed a metaphor depicting a journey metaphor. Typical journey metaphors included

Table 3
Preservice Elementary/Early Childhood Teacher Metaphor

Time	Production	P/J	Journey	J/G	Growth
No math methods	62%	4%	19%	0%	3%
1 math method	48%	19%	15%	3.5%	2%
2 math methods	52%	17%	10%	12%	5%

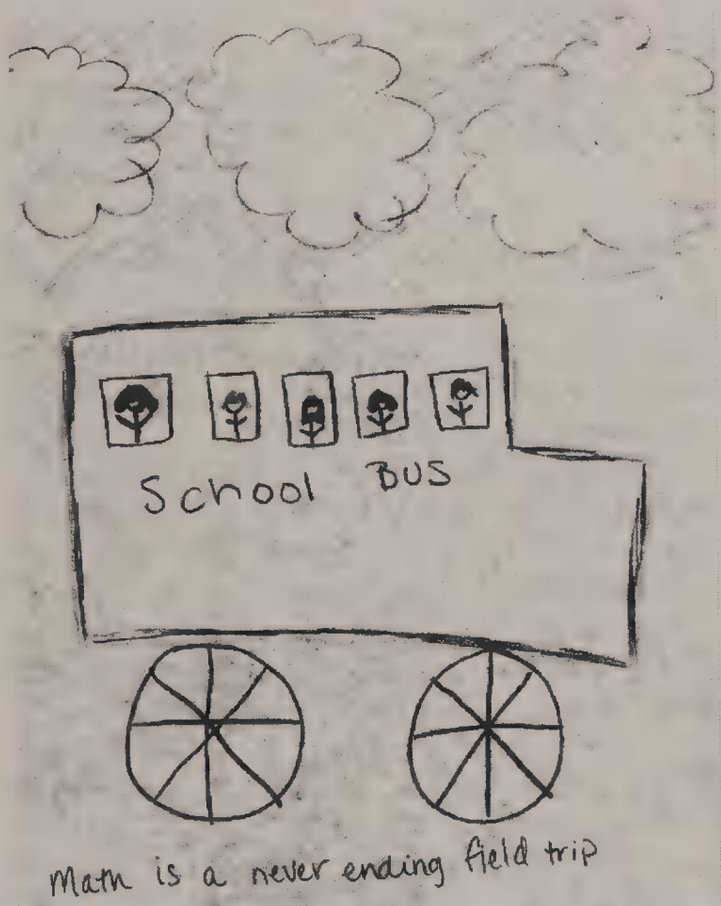

Figure 2. Sample journey metaphor.

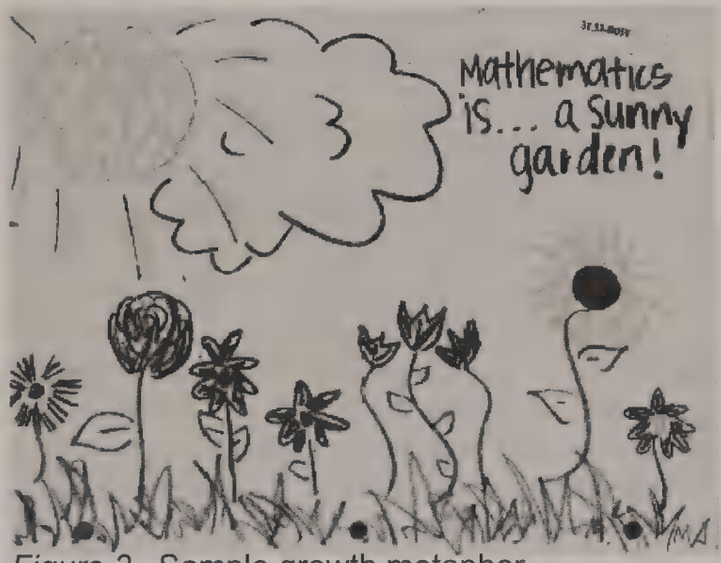

Figure 3. Sample growth metaphor.

Mathematics is ... a never ending field trip (see Figure 2), *... a bumpy road*, *... a long hard journey*, and *... an adventure*. Metaphors categorized as journey depicted either in writing or pictorially the teacher as a guide or leader of an adventure with students actively participating in the journey. Many also indicated that the teacher continually learns with the students as things are discovered.

The growth metaphor for mathematics teaching and learning was represented in the fewest number of metaphors with only 3% to 5% of all metaphors across the three participant groups falling in this category. Typical growth metaphors included *Mathematics is … a sunny garden* (see Figure 3), *... a plant*, *... a blooming flower*, and *... a tree*. Metaphors categorized as growth depicted the teacher as one who gives something to the students that they need but can use in their own way. The teacher is a nurturer working with students who are curious life-long learners.

While the majority of all metaphors collected from the three participant groups clearly depicted a production, journey, or growth metaphor there were several that reflected aspects consistent with a combination of two metaphors. For example, one metaphor *Mathematics is ... a company* (see Figure 4) reflected aspects of both a production and a journey metaphor. The student stated that "[t]he teacher is the president. She is the head of the class, but works side-by-side, hand-in-hand with all of the employee/students" indicating that the teacher is in charge, giving knowledge to the students (production) but also working alongside the students (journey). Likewise, another metaphor, *Mathematics is a ... flower garden* (see Figure 5), depicts aspects consistent with both the journey and growth metaphors. The preservice teacher states in this metaphor that students "… have everything they need to learn and grow… [but] … the teacher is the rain which helps and guides the students or the flowers." Overall, these mixed metaphors comprised 4% to 29% across all the participant groups.

Examining the types of metaphors depicted (see

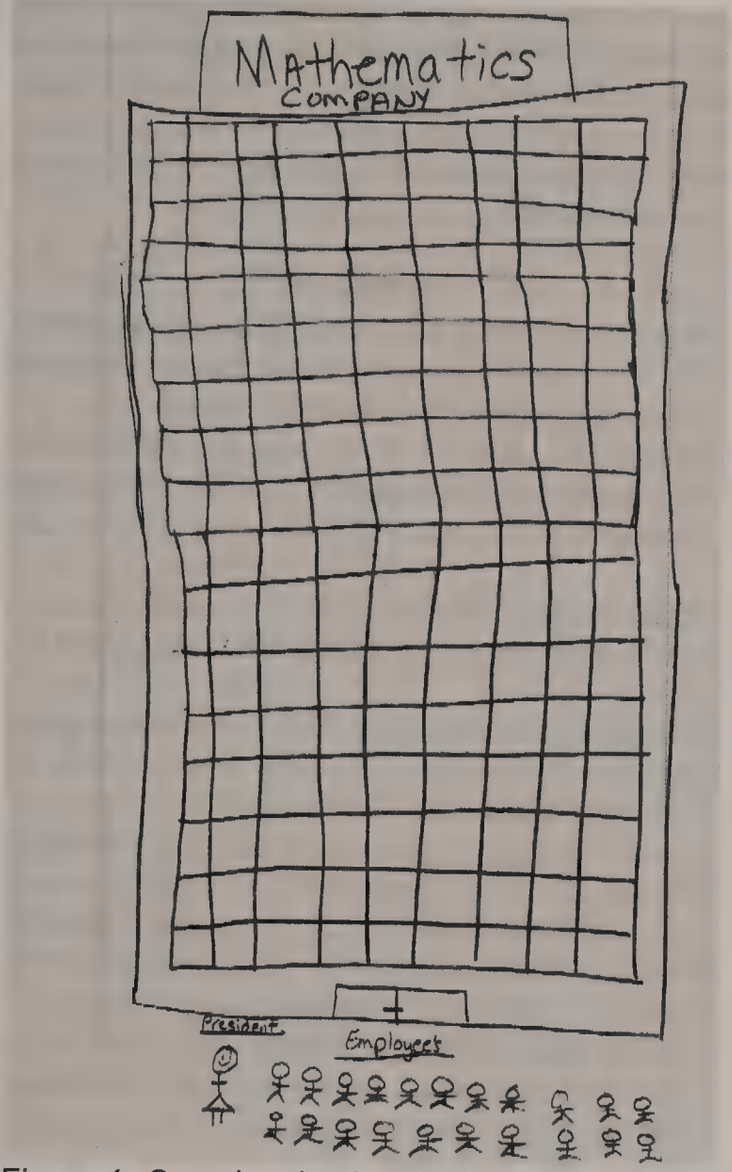

Figure 4. Sample mixed metaphor: production/ journey.

Figure 5. Sample mixed metaphor: journey/ growth.

Table 3), reveals that while the types of metaphors did not differ significantly there was a slight 10-12% decrease in the number of production metaphors and a slight increase of between 13% and 15% for the mixed metaphor production/journey after participants had taken at least one mathematics methods course. Additionally, there was a small decrease of 4-9% in the number of journey metaphors and a small increase in the number of mixed journey/growth metaphors after participation in at least one mathematics methods course. The number of growth metaphors fluctuated 1-2% across the three groups. The most notable difference was the decrease in the number of production metaphors from 62% of the preservice teachers constructing metaphors depicting a production metaphor prior to their experiences in mathematics courses to 52% constructing metaphors depicting a production metaphor following their experiences in both mathematics methods courses. This seemed to indicate that experiences in mathematics courses had minimal impact on these elementary preservice teachers' beliefs about mathematics teaching and learning.

Conclusions

Throughout their teacher education program the participants in this study were involved in multiple and ongoing opportunities to reflect on their experiences working with children in schools, tutoring children, and practice teaching in all their professional education coursework. Likewise, these participants were actively involved in two mathematics methods courses where they experienced further opportunities to specifically examine and reflect on their beliefs about mathematics teaching and learning as they participated in learning opportunities and activities aligned with and supportive of constructivist theories about learning. Throughout

both these courses, the teacher educators teaching these classes continually challenged preservice teachers' beliefs about teaching and learning asking them to reflect on their own experiences as learners and what they were learning through readings, research, coursework, and their experiences in schools. Despite opportunities to continually and actively reflect throughout their coursework and their learning and teaching mathematics experiences using approaches more supportive of and in alignment with constructivist theories of learning, the results of this study indicated that the preservice teachers' beliefs about mathematics teaching and learning, as depicted in their metaphors, remained relatively static. However, minimal differences were noted across all three participant groups with a slight decrease in the number of preservice teachers who constructed production metaphors and slight increases in the number of students who depicted the production/journey, journey/growth, and growth metaphors (see Table 3). If these metaphors are considered to represent a continuum from production to journey to growth with production being aligned with more traditional teacher centered approaches and growth reflecting teaching practices more aligned with constructivist theories of learning then the reflective practices and experiences in this teacher education program had minimal impact in its efforts to bring about a shift in these preservice teachers beliefs about mathematics teaching and learning. While these results revealed what we might have expected based on research about the teaching practices of beginning teachers they are nonetheless significant because they call us to critically examine our role as mathematics teacher educators in bringing about significant change. Our efforts to support reform in mathematics education may not make a significant difference during the time that our preservice teachers are with us in our mathematics methods courses.

In concert with Dewey's desire, Loughran (2002) suggests that a goal of many teacher education programs is to develop reflective practitioners and that reflection can be a meaningful way to examine one's beliefs about teaching. Additionally, Loughran stresses the importance of effective reflection. This study reveals that metaphors may prove to be an effective tool to help teacher educators examine and reflect on the beliefs of their preservice teachers about teaching and learning mathematics. Likewise, metaphors may prove to be a useful tool for preservice teachers to reflect on and examine their own beliefs about mathematics teaching and learning and thus help bring about change in those beliefs. Further, this study indicated a need for teacher educators to examine and reflect on their practices and role in the ongoing efforts for change in mathematics teaching and learning for both their preservice teachers and their future students.

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Mathematical Habits of the Mind for Preservice Teachers

This article provides an overview of mathematical habits of the mind and discusses how the concept relates to Polya's problem solving principles as well as exemplification. Specific problems are discussed as a means to assist preservice elementary school teachers' in their development of mathematical habits of the mind. Without a technique to begin solving these rich problems, preservice teachers may have difficulty getting started. The process of preservice teachers outlining their thinking as they progress through Polya's process is discussed. Students' reflections from this technique are discussed to explore the outcomes that may be expected from establishing an environment where students are encouraged to develop mathematical habits of the mind.

An approach to promoting mathematical habits of the mind is to develop a culture of sound mathematical questioning in present and future teachers that will allow them to challenge themselves and their students at an appropriate level. An overview of mathematical habits of the mind will be provided followed by problems that may help preservice teachers think about mathematics differently. Finally, a specific strategy will be discussed to help students think about how to get started with rich mathematical problems. Preservice teachers' reflections upon their experiences provide a valuable lesson regarding how this technique may help preservice teachers (and their future students) develop mathematical habits of the mind. While we believe that this approach is appropriate at all levels, in order to narrow the scope of this article, the focus of this paper will be on infusing the idea of a mathematical habit of the mind in the preparation of future elementary and middle school teachers.

Overview of Mathematical Habits of the Mind

To help their own students be more creative, teachers need to work with their students to:

1) explore mathematical ideas;
2) formulate questions;
3) construct examples (Watson & Mason, 2005);
4) identify problem solving approaches that are useful in large classes of problems;
5) ask themselves whether there is "something more" (a generalization) in the mathematics on which they are working;
6) reflect on their answer to see whether they have made an error (Jacobbe, 2007). These traits can be called "mathematical habits of the mind" which is a term that is featured prominently in an important teacher education report from the Mathematical Association of America (Conference Board of the Mathematical Science [CBMS], 2001). Furthermore, the process standards set forth in the *Principles and Standards for School Mathematics* (National Council of Teachers of Mathematics [NCTM], 2000) include problem solving, communication, reasoning and proof, making connections and representations. These processes can be described as mathematical habits of the mind.

Problem solving is at the heart of mathematical habits of the mind. In *Benchmarks for Science Literacy*, The American Association for the Advancement of Science (AAAS) indicated that "preparing students to become effective problem solvers, alone in concert and with others, is a major purpose of schooling." (AAAS, 1993, p. 282) One of the first mathematicians to clearly articlulate the process of problem solving was George Polya. Polya's (1956, 1973) foundational writing on problem solving involves the creation of mathematical habits of the mind, although he does not use the phrase. The Polya method consists of four steps: understanding the problem, devising a plan, carrying out the plan, and looking back (Polya, 1973).

It is the "looking back" step that is very much the heart of mathematical habits of the mind as described above. "By looking back at the completed solution, by reconsidering and re-examing the result and the path that led to it, they [students] could consolidate their

knowledge and develop their ability to solve problems" (Polya, 1973, pp. 14-15)." In *Benchmarks for Science Literacy*, the AAAS emphasized the importance of reflection as well.

> Learning to solve problems in a variety of subject-matter contexts, if supplemented on occasion by explicit reflection on that experience, may result in the development of a generalized problem-solving ability that can be applied in new contexts; such transfer is unlikely to happen if either varied problem-solving experiences or reflection on problem solving is missing. (AAAS, 1993, p.282)

Jacobbe (2007) used the looking back or reflection step as a way to help structure students' thinking in order to overcome translation difficulties. Reflections from students' experiences with this approach are shared later in the article as a means to articulate a method to help students develop mathematical habits of the mind.

Clemens (1991) was one of the first mathematicians to advocate that, in order for teachers to be successful, they must create an environment that promotes mathematical thinking. Mathematics is not about all the rules and procedures that must be memorized and regurgitated by students; rather, it is about developing a process for approaching various problems. Clemens argues that two equally successful teachers could choose entirely different sets of problems to center their curriculum around as long as they have "mathematical integrity and equal relevance to quantitative experiences and questions that are natural to human beings "(Clemens, p. 87).

A review of the literature has revealed no studies on this subject except for those which are revolve around exemplification (See Watson & Mason, 2005). There have been discussion pieces centered at the high school level (See Cuoco, Goldenberg, & Mark, 1996; Cuoco, 2001). The idea of "exemplification in mathematics" fits in well with the notion of mathematical habits of the mind. Watson and Mason carefully explain the framework, application, history, and research base of this approach.

> Example creation can provide an arena not only for practice but also for conceptual learning…With every construction there is also a question: How much choice do I have? Mathematicians typically pursue this by then asking whether they can characterize all such examples in some way. (Watson & Mason, p. 13)

This strategy consists of having learners construct their own examples as a way to give insights into more advanced ideas. "No matter how profoundly one thinks one understands, it is always possible to probe more deeply and to discover more connections and complexities (Watson & Mason, p. xiv)."

In order to foster mathematical habits of the mind, it is important to pose questions that allow for multiple solution paths. The following is an example of a high school mathematics problem posed to mathematicians by Watson and Mason:

> We have decided to call the horizontal distance between neighboring roots *f* a polynomial function the inter-rootal distance. Imagine a quadratic equation with two real roots. What families of quadratic curves have the same inter-rootal distance? (Watson & Mason, 2005, p. 40)

In their discussion of this example Watson and Mason revealed the variety of methods that the mathematicians came up with. The authors relate the solutions to the background and area of specialization of the mathematicians. One used dynamic software packages and another found one member of the family and then, with some thought, used translation and stretching the y-axis. Two of the conclusions of Watson and Mason (2005) are: "Example creation is individual" (p. 41) and "Being a mathematician includes being able to question one's first response and seek alternatives, searching algebraically, geometrically, and in other ways to find as many examples as one can" (p. 42).

Mathematical habits of the mind, as outlined in this paper, do not require a deep mathematical background, only an inquiring mind that will focus on thinking in a mathematically creative way. Nor does it have to be something new to the world or even ideas that are novel or innovative — rather focusing on the creation of mathematical habits of the mind is a way to structure, infuse, and talk about some aspects of mathematics.

Examples of Mathematical Habits of the Mind at the Elementary and Middle School Level

This section presents problems that can be used to promote mathematical habits of the mind among preservice teachers. It is important for preservice teachers to experience these types of problems so that they may know how to create an environment that pushes their future students' thinking.

The following example was given in a content

course on problem solving for elementary and middle school teachers. After proving that the sum of even numbers is even, the sum of odd numbers is even, etc., the class was asked to show that the product of even numbers is even. At the end of that in-class group exercise, the instructor asked the students to think back on what happened and whether there was anything more going on. After more conversations in their groups, and a series of hints from the instructor to some of the groups,the future teachers realized that the product was actually divisible by four, not just two and that, as one of them said, "the result is free" meaning that the same proof worked for the stronger result. We have given similar "is there more?" questions, such as ones concerning the square of an odd number, in the content math course required of all future elementary school teachers.

In the same course, students were also asked to show that a certain polynomial expression in the integer n is divisible by 4, 8, 16 or 32. An example of this type of problem is as follows:

> Let n be an odd integer. Show that 16 divides $(n^2 + 4n - 1)(n^2 + 4n + 3)$. Does 32 divide the expression? (Millman, 2007)

Average students can do the first question and can show that 32 also divides the expression in special cases. The top 20% of the class was able to write out a proof of divisibility by 32 by using algebra. The division by 16 is "low hanging fruit" (just follow the algebra) but division by 32 requires an insight (that, after simplifying, there is a product of 16 and two consecutive integers). Said another way, insights and a conceptual understanding are very much examples of mathematical habits of the mind, whereas routine computation is not.

Fermi Problems, which are open-ended or vaguely worded problems, would also foster the development of mathematical habits of the mind since they require students to examine how they would model a situation (see Peter-Koop, 2005). Preservice elementary school teachers in a mathematical content course have found these types of problems quite intriguing and are delighted to see what German fourth grade students do on the problems.

Another example of a problem that may help preservice teachers develop mathematical habits of the mind can be shown by three exercises which present the same idea in three different ways as follows:

a. Find all pairs of prime numbers that sum to 313.

b. If k is an odd number, what possible pairs of prime numbers can sum to k?

c. If k is an odd number, show that there are either no prime numbers which sum to k or only one pair of primes that sum to k.

Future elementary school teachers have been asked to compare these questions to demonstrate an example of insights along the lines of mathematical habits of the mind. Although the first question may seem easier to get started with to a preservice elementary school teacher, the second two questions are actually easier to answer. The first question requires the insight that the real point is that 313 is odd. While these are phrased as questions (or prompts), not examples, the analogies between this type of exercise and the approach of Watson & Mason (2005) are clear.

Two other examples, which come from a textbook designed for future elementary school teachers, are provided below. The first asks preservice teachers to recognize what it means for a statement to always be true and see that algebra can be used for this purpose. The notion of algebra as a way of proving conjectures is a mathematical habit of the mind. The first problem is:

> A student has noticed that every squared natural number is either a multiple of 4 or one larger than a multiple of 4, but isn't sure if this is always true. Use algebraic reasoning to explain to the student why this is always true (Long, DeTemple, & Millman, 2008).

Another example of a problem that promotes the development of mathematical habits of the mind follows from a paragraph in the text, which is neither an example nor an exercise, and asks preservice teachers to think about the relationships between two different concepts. In this case, the ideas underneath the prose are that we can derive a formula by relating two quantities which seem unrelated and that areas or volumes can be approximated by very small areas or volumes.

> We will now derive a formula for the surface area of a sphere of radius r by making use of the formula that we already know for the volume of a sphere. This derivation is done through reasoning, rather than by formal proof, as is the approach of this chapter. The key concept will be to relate the volume of the sphere to the volume of pyramid-like solids whose base is a small piece of the surface. We first divide the sphere's surface into many

tiny regions of area…(Long, DeTemple, & Millman, 2008, p. 286)

The problems discussed above are interesting and may help preservice teachers; however many students struggle with how to begin when presented with problems where the solution methods are not straightforward. One technique that can be employed to help preservice teachers think about mathematics differently is to require students to outline their thinking as they progress through each of Polya's steps in the problem solving process. Particular attention should be paid to students' outlining their thinking at the "looking back" stage in the process. As described above, the "looking back" stage is at the heart of mathematical habits of the mind. Jacobbe (2007) showed how this technique can greatly improve students' performance on translation tasks (incorrect response rate reduced from 79 to 14 percent). As exhibited through students' reflections, this technique may also empower preservice teachers to think about mathematics differently.

Students Reactions to Progressing through Polya's Steps

The process of outlining their thinking at each of Polya's steps required the students to really think about what they were doing. Many students struggled with where to begin; however Polya's first step "understanding the problem" often helped them "devise a plan." This activity of progressing through the steps has the potential to impact preservice elementary school teachers' future approaches to teaching mathematics in the classroom. The impact of progressing through the steps is evident in the following students' responses to a question regarding the impact of progressing through Polya's steps as they solved several problems.

> Math has always been a hard subject for me. However, I have the most difficulty with word problems. With these steps, I can figure out how to do the problems effectively.

Student Response 1

> This process would help me solve other problems that I would have difficulty with. By following these steps one is forced to analyze and outline each area of a problem. This not only breaks the problem down to seem simpler, but enables the problem solver to visually catch his/her mistakes or point out where he/she may have gotten stuck. It also makes it easier to go back and check final answers.

Student Response 2

> The process would help with any problem that would otherwise be difficult. It makes it easy to see what you need to do when you follow each step carefully. You can see the problems in different ways than you may have thought of. The problems may be simpler than you originally realized. The steps can help you see everything in the easiest way possible.

Student Response 3

> Initially, I felt that progressing through each step of the word problems was time consuming and repetitive. However, I realized that learning and carrying out these steps in each of the problems is important for elementary school students as well as teachers. Each step in the problem solving process is important to understanding the problem fully. When a student comes in contact with a difficult problem, it is necessary for him/her to complete the steps to come out with a correct answer and a full understanding. Also, the problem solving process will help teachers be able to explain their answer more effectively. I have come to realize that even though completing all the steps may be time consuming, it is an effective way to solve problems.

Student Response 4

> The impact of having to progress through each step in Polya's process is most evident in Student Response 4. This particular student realized the importance of students and teachers outlining their thinking as they work through various problems. This technique may provide preservice teachers with a means to get started on many of the problems discussed above. Once they are free to think about the mathematics involved, they may begin to develop the mathematical habits of the mind discussed in this paper.

End Remarks

The importance of developing mathematical habits of the minds is exemplified by the contributions of Fields Medalist, Andrew Wiles. His early acquaintance with Fermat's Last Theorem and his internal desire to seek a solution sparked a career that led to solving a problem that had remained unsolved for hundreds of years. According to Wiles, "The definition of a good

mathematical problem is the mathematics it generates rather than the problem itself" (Nova, 2000, p. 1). Rich problems along with a technique to get them started will help preservice teachers and their future students develop mathematical habits of the mind. These habits have the power of launching internal inquisitiveness that may lead to creative mathematical discoveries.

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Technology-Based Inquiry for Middle School
Editor: Edwin P. Christmann

NSTA Press
1840 Wilson Blvd.
Arlington, VA 22201-3000

2006; 134 p.
Paperback, unknown cost

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Technology-Based Inquiry for Middle School is an idea book to help middle school science teachers integrate innovative technology into their classroom activities. The book is a collection of previously published articles from NSTA's *Science Scope*, the journal for middle school science teachers. The book is divided into five sections, with the first section devoted to a broad description of scientific inquiry. The next three sections cover specific ideas for using technology to integrate inquiry into physical science, earth and space science, and life sciences. Five to ten chapters compose each section and are focused on various topics in which technology can be integrated into the content. The last chapter is on general science and technology applications, and covers general topics such as graphing calculators, personal digital assistants, Internet research, technology to assist special needs students, grade book software, and computer-assisted instruction. The chapters are short and easy to read. Each chapter contains related National Science Education Standards, references, and Internet resources.

Chapters in each of the three subject area sections either deal with an area of broad concern, such as classroom GPS applications, or with specific ideas for teaching a scientific concept, such as volcanoes or meteorology. For example, in the physical science section, Chapter 1, "Time for Class," is a short historical essay on how time is measured. The focus here is not on a classroom lesson plan, but on providing Internet resources about this topic. Chapter 3, "A Different Phase Change," is a detailed procedure for a teacher demonstration using a CBL2 and graphing calculator to investigate the melting/freezing point of stearic acid. The chapters are short and easy to read and are correlated to the NSES.

While the chapters on physical science and biology are not particularly inspired, there are a number of good chapters on using technology to integrate inquiry into earth science. The chapter on temperature forecasting is one of the better chapters that integrates probeware to answer the question "Is the temperature forecast provided by www.weather.com reliable?."

Chapters are short, ranging from two to four pages, and easy to read. This is a benefit to teachers interested in an overview and not in detail. While some procedures are detailed, most chapters are merely outlined. This book may inspire teachers to begin thinking about integrating a particular technology, but teachers will need additional detailed information and/or training to be able to use the more technical instruments such as CBL, GIS and PDAs.

Another limitation is that Internet resources are not annotated. For teachers with limited time, this means they will have to forage through these resources without benefit of knowing what each site might offer. Several pictures, especially in Chapter 8 on GPS applications, are dark, grainy and pixilated.

For teachers looking for inspiration of how to increase the use of technology in middle school science, this book is a great resource. It gives teachers a vision of scientific inquiry that is broader than traditional controlled experimental science. This introduction to a broader view of inquiry is particularly important for teachers of subjects such as earth science, because earth science deals with large systems in which variables cannot be manipulated or controlled.

The editor, Edwin Christmann, has developed a supporting website to assist teachers with the technology in the book and to provide additional information such as chapter reviews, outlines, sample test questions, related activities and PowerPoint presentations to help teach information in the book.

Constellations Dot-to-Dot
Authors: Evan and Lael Kimble; Illustrated by Richard Salvucci

Sterling Publishing Co.
387 Park Avenue South
New York, NY 10016-8810

2001; 80 pages
Soft cover: $5.95

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Constellations Dot to Dot, by Evan and Lael Kimble, is as its name implies, a connect-the-dots experience of the major constellations. The book includes forty full-page, dot-to-dot illustrations for connecting and coloring. The illustrations, organized by "Fall," "Winter," "Spring," "Summer," and "Southern Pole Stars," are clear and detailed, with several ranging up toward the 200-dot level. Readers are also invited to "Draw Your Own Constellations" on a two-page spread illustrating the major stars in the entire night sky.

Along with each constellation presented there is a fact page, containing such information as the constellation's legend, number of stars, special stars, and star facts. These associated details are necessarily brief, given the one-page format, but interesting, especially the mythological and historical background facts. In this sense, the book offers some good cross-disciplinary study opportunities. Other than the dot-to-dot number lines, there are essentially no math connections.

Constellations Dot to Dot provides simple puzzles with bits of associated information, but for those looking for more expansive options, the book is limited. For example, the book doesn't offer any general suggestions for instructional use, nor does it provide enough information to help young scientists readily locate the various constellations in the night sky. Further, the connect-and-color aspect of the book is geared for younger students, while the reading level is more appropriate for older students.

Another age-related problem exists that is likely to confuse some younger readers. The stars that make up any constellation, of course, only roughly determine the shape of that constellation's mythological image. For example, the book's connectable dots describing the shape of Andromeda's image must be far more extensive, and differently shaped, than the rough image described by the eight fundamental stars within Andromeda. This creates something of a problem for younger readers, most of whom are bound to be concrete-operational thinkers. The night stars do not create as distinct an image of Andromeda, Ursa Major, Delphinus, or any other constellation as the connect-the-dots format might suggest to concretely perceiving, elementary-level students. Further, the book does not make a point to readers that the connectable dots represent only the border of the constellation's image, not specific stars in that constellation. In other words, younger readers are likely to confuse the connectable dots with the constellation stars. An alert teacher or parent could certainly make that point, but this confusion is likely to complicate the young reader's understanding of constellations' shapes, and potentially make it more challenging to actually find the shapes in the night sky.

Nevertheless, *Constellations Dot to Dot* will be a nice resource for kids hungry for astronomical facts. The book can reinforce the general shapes of the constellations, and despite the limitations noted above, assist students to some extent in finding those shapes in the night sky. Although the book offers some interesting information, its lack of content-use connections severely limits its classroom utility. All things considered, it could be of value in some grade 3-5 classes as a supplement for independent astronomical studies, or as an opportunity for marginally engaging, rainy day style seatwork.

PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to: Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel; or fax to:972-86-477-648. Questions concerning proposals and/or solutions can be emailed to: eisenbt@013.net. Solutions to previously stated problems can be seen at: ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before October 15, 2009

5068: *Proposed by Kenneth Korbin, New York, NY.*
Find the value of

$$\sqrt{1+2009\sqrt{1+2010\sqrt{1+2011\sqrt{1+\cdots}}}}.$$

5069: *Proposed by Kenneth Korbin, New York, NY.*

Four circles having radii $\frac{1}{14}, \frac{1}{15}, \frac{1}{x}$ and $\frac{1}{y}$ respectively, are placed so that each of the circles is tangent to the other three circles. Find positive integers x and y with $15 < x < y < 300$.

5070: *Proposed by Isabel Iriberri Díaz and José Luis Díaz-Barrero, Barcelona, Spain.*
Find all real solutions to the system

$$\left.\begin{aligned} 9(x_1^2+x_2^2-x_3^2) &= 6x_3-1,\\ 9(x_2^2+x_3^2-x_4^2) &= 6x_4-1,\\ &\cdots\cdots\\ 9(x_n^2+x_1^2-x_2^2) &= 6x_2-1. \end{aligned}\right\}$$

5071: *Proposed by José Luis Díaz-Barrero, Barcelona, Spain.*

Let h_a, h_b, h_c be the altitudes of ΔABC with semi-perimeter s, in-radius r and circum-radius R, respectively. Prove that

$$\frac{1}{4}\left(\frac{s(2s-a)}{h_a}+\frac{s(2s-b)}{h_b}+\frac{s(2s-c)}{h_c}\right)\le\frac{R^2}{r}\left(\sin^2 A+\sin^2 B+\sin^2 C\right).$$

5072: *Proposed by Panagoite Ligouras, Alberobello, Italy.*
Let a, b and c be the sides l_a, l_b, l_c the bisectors, m_a, m_b, m_c the medians, and h_a, h_b, h_c the heights of ΔABC. Prove or disprove that

a) $$\frac{(-a+b+c)^3}{a}+\frac{(a-b+c)^3}{b}+\frac{(a+b-c)^3}{c}\ge\frac{4}{3}\left(m_a\cdot l_a+l_b\cdot h_b+h_c\cdot m_c\right)$$

b) $3\sum_{cyc}\frac{(-a+b+c)^3}{a}\geq 2\sum_{cyc}\left[m_a\left(l_a+h_a\right)\right]$.

5073: *Proposed by Ovidiu Furdui, Campia-Turzii, Cluj, Romania.*
Let $m>-1$ be a real number. Evaluate

$$\int_0^1\{\ln x\}\,x^m dx,$$

where $\{a\}=a-[a]$ denotes the fractional part of a.

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2. To maintain anonymity of the author(s), author(s) citing their own work should cite as follows:
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IN THIS issue

Research in Brief

Students' Understandings and Misconceptions of Algebraic Inequalities

Rebecca V. Rowntree

The National Council of Teachers of Mathematics [NCTM] requires students in grades nine through twelve to be able to explain inequalities using mathematical relational symbols and be able to understand the meaning of inequalities and their solutions (NCTM, 2000). Studies have shown that not only middle and high school students have difficulties with inequalities, but those of college age as well, particularly in the following four areas: a) regarding inequalities as equations (Vaiyavutjamai & Clements, 2006; Blanco & Garrote 2007), b) a limited understanding of the terms "more" and "less" and of the corresponding relational symbols (Warren, 2006), c) difficulties relating and using different solving techniques (Tsamir & Almog, 2001; Blanco & Garrote, 2007), and d) interpreting solutions (Tsamir & Bazzini, 2004).

Research Articles

Constructing Elementary Teachers' Beliefs, Attitudes, and Practical Knowledge Through an Inquiry-Based Elementary Science Course

Sanghee Choi, John Ramsey

This study examines inservice elementary school teachers' beliefs, attitudes, and practical knowledge toward inquiry-based science instruction and the influence of an inquiry-based elementary science course on teachers' beliefs, attitudes, and practical knowledge regarding inquiry. Both surveys and a case study were administered to the 14 elementary school teachers before and after completing a three-credit elementary science methods course that was inquiry-based. The findings showed that the teachers' beliefs, attitudes, and practical knowledge about inquiry were clearly influenced by the course. Through this course, the teachers developed fairly positive beliefs and attitudes that promoted inquiry instruction. The majority of participants also improved their knowledge and skills of conducting inquiry as they successfully practiced inquiry-instruction in their science teachings.

Computational Estimation Performance on Whole-Number Multiplication by Third- and Fifth-Grade Chinese Students

Fuchang Liu

Four hundred and three 3rd- and 5th-grade Chinese students took the Multiplication Estimation Test or participated in the interview on it, designed to assess their computational estimation performance on whole-number multiplication. Students perform better when tasks are presented visually than orally. Third graders tend to use rounding based while fifth graders tend to use written algorithm based strategies, but boys' and girls' performances do not differ. It is concluded that students often will not estimate simply at the request to estimate if an exact answer is within their mental computation capability, and a two-step process is suggested for helping students decide what route to take when given arithmetic problems.

Beginning Mathematics Teachers' Beliefs of Subject Matter and Instructional Actions Documented Over Time

Gili Marbach-Ad, J. Randy McGinnis

In this study we report the results of survey research that collected responses of an identical sample (31 beginning mathematics and science teachers, elementary and middle school level) that graduated from a reform-based mathematics and science teacher preparation program, the Maryland Collaborative for Teacher Preparation (MCTP). Our aim was to compare responses of the same beginning teachers over the two administrations of the survey. We administered the identical survey instrument in two separate batches spreading over nearly a four-year period (1st batch fall 1999 through fall 2001; 2nd batch summer 2002). The first administration (pre-test) was conducted soon after the beginning teachers graduated from the teacher preparation program and had not started full teaching. The second administration (post-test) was conducted after the new teachers had taught full time for a minimum of a full year, with the majority having taught for two years. The instrument was crafted to measure the constructs of interest, MCTP Teacher's Beliefs and Actions of Mathematics and Science. Results for teachers who taught for at least two years indicated that in all areas the MCTP teachers maintained their reform-based beliefs and actions after their induction years. These findings provide evidence for the sustainability

of positive impact in the workplace resulting from a reform-based undergraduate teacher preparation program.

Research in the Classroom

Preservice Teachers' Analysis of Children's Work to Make Instructional Decisions

Sandi Cooper

Teaching is an interactive process in which teachers gather information, analyze the results, and construct a response based on this diagnosis (Cooney, 1988). Considering alternatives in constructing a response, that is, making an instructional decision, is of great importance in teaching. How might mathematics teacher educators provide experiences for preservice teachers to begin the development of this skill? In an attempt to determine how these experiences might reveal the level of understanding preservice teachers have in regards to children's mathematical thinking, a study was conducted over three semesters. During the mathematics methods course, preservice teachers were involved in analyzing children's work through the review and discussion of several samples. They were required to determine the error pattern, discuss what might have lead to this misconception, and suggest appropriate instructional strategies that might help this student. Although most preservice teachers could correctly identify the computational error patterns, they had difficulty in determining what might have led to the misconceptions and proposing effective instructional strategies.

editorial

Gerald Kulm, *Texas A&M University*

Science and Mathematics Education in a Context of National Crises

We enter another new school year in a context of enduring questions not only about U. S. science and mathematics education but also about the direction and stability of the nation's economy. Although it is not at all clear how the current administration will focus its efforts for continuing education reform, there is talk about voluntary national standards, competition among states, and teacher merit pay. However, the attention to education competes with seemingly more pressing national problems with the economy, unemployment, debates about health care, and concerns about global warming. The funding available for education, including science and mathematics, is at record levels due in large part to efforts to stimulate the economy through massive injections of federal money. However, the economic problems faced by state and local officials may force them to use these funds simply to keep schools running rather than on reform or innovation as intended.

The economic crisis may have diverse effects on education, although is difficult to assess the current an d potential impact. The effects may be seen from the individual student level all the way to state and national leadership. Students whose parents are among the record number of unemployed persons can be affected in their attention and focus on school work. Some teachers might be dealing with larger classes, reduced supplies, or concerns about their own jobs. Local, state, and national leaders are faced with larger budgetary issues. Any or all of these concerns can have a priority that places them ahead of planning or implementing new strategies or reforms in science or mathematics teaching and learning.

On the positive side, education is an enduring and necessary component of the nation's life. Those of us who are educators are fortunate that our jobs are less at risk than most other professions. Although we don't often experience bonuses and other perks of economic booms, we also don't often face the prospect of layoffs on short notice. Every new school year brings with it the opportunity to start anew and have lasting impact on people's lives. Even in difficult times, the classroom offers a calm and safe place for teachers and students to look to the future. It is even more important now that teachers communicate and that students recognize the power of a solid educational preparation. Knowledge and skill in mathematics and science is more essential than ever for future employment and advancement opportunities.

Times of crisis are indeed times of opportunity as well. Much of the current thinking seems to be that the federal government has the primary role in addressing the nation's problems. The rush to implement change and push through government-mandated solutions has already been evident in the past year. There are, however, other modes and sources of expertise and policy. Science and mathematics education has for the past 20 years offered a model in which professional societies have taken on successful leadership roles in developing standards and directions for improvement and reform. These organizations have the advantage of taking a longer view and not depending on "quick fixes" that are often the goal of government-led activities.

National standards, curriculum, and assessment are extremely important changes that should not be implemented in a context of a rush to spend appropriated money on a short time schedule. In the current context, there is a danger that educational reform strategies proposed by the federal government can become politicized. Experiences from the past have shown that the most noble of motivations by politicians often result in partisan arguments that lead to barriers in implementation.

As discussions begin regarding national standards and further attention to national tests, it is likely that mathematics and science will, as in past efforts, be the focus and first choice for attempts to implement these reforms. Science and mathematics education leaders and organizations have the responsibility to step for-

ward and provide a voice of reason and evidence-based leadership on these issues. These leaders must try their best to eschew partisan ideas and base their recommendations and work on solid evidence. The current crises provide the chance for education to once again be recognized as the foundation for the nation's future success.

RESEARCH IN
brief

Rebecca V. Rowntree
Texas A & M University

Students' Understandings and Misconceptions of Algebraic Inequalities

The National Council of Teachers of Mathematics [NCTM] requires students in grades nine through twelve to be able to explain inequalities using mathematical relational symbols and be able to understand the meaning of inequalities and their solutions (NCTM, 2000). Studies have shown that not only middle and high school students have difficulties with inequalities, but those of college age as well, particularly in the following four areas: a) regarding inequalities as equations (Blanco & Garrote 2007; Vaiyavutjamai & Clements, 2006), b) a limited understanding of the terms "more" and "less" and of the corresponding relational symbols (Warren, 2006), c) difficulties relating and using different solving techniques (Tsamir & Almog, 2001; Blanco & Garrote, 2007), and d) interpreting solutions (Tsamir & Bazzini, 2004).

Vaiyavutjamai and Clements (2006) conducted a study using 231 ninth-grade students. They found that the students often treated inequalities as equalities and demonstrated confusion of the meaning of solutions to inequalities. These researchers claimed that in lessons on inequalities, instruction was brief, minimal links between algebraic inequalities and their use in daily life were made, and while symbol manipulation was taught, less time was spent discussing the meanings of the symbols being used and of the manipulations.

A similar study by Blanco and Garrote (2007), in which 91 students in their first year of university studies participated after having received instruction on algebra and inequalities, the researchers found that "Many students understood the greater than and less than signs to be a nexus between two algebraic expressions. They then carried this nexus through the various steps in solving an inequality without attaching any meaning to it, even to the point of simply substituting and equals sign" (p. 224). The students' treatment of inequalities as equalities led many to fail to understand the solution they found; they had trouble understanding which values made the inequality true and which ones did not (Blanco & Garrote). Pre-service teachers at the end of their university studies may struggle with these same difficulties, passing their own misunderstandings to their students. Shaughnessy (1992) emphasizes that "we have to first deal with teachers' misconceptions before we can expect them to be competent at helping their students to overcome misconceptions" (p. 484).

According to Usiskin (1996), "If a student does not know how to read mathematics out loud, it is difficult [for him or her] to register the mathematics" (p. 236). Much of students' confusion about inequalities can be attributed to their lack of a complete understanding about the terminology used to describe inequalities—words like "less than," "greater than," "at least," "at most," "no more than," etc. Teachers often hurriedly brush over the terms "more" and "less" as used in a mathematical context (Warren, 2006). Warren conducted a longitudinal study in Queensland, Australia over a period of three years to determine how students were being taught the mathematical language associated with algebraic inequalities. During this time, she analyzed the mathematics textbooks used in the first five grades of primary school and discovered that only five percent of material aimed to develop a mastery and understanding of the concepts of the terms "more" and "less." She developed a framework that outlined students' progression in understanding the terms. Warren claimed that students fail to operate at the highest level of understanding the terms because most classroom instruction focused on arithmetic procedures that involved solving number or word problems with addition and subtraction. These arithmetic lessons with "more" and "less" were not necessarily transferable to working with the same terms and concepts in algebra.

Students also have difficulties with using various representational methods to solve or represent inequalities. Tsamir and Almog (2001) found that students use algebraic manipulations most often when solving inequalities; however, they found that this technique led to the highest rate of incorrect solutions compared to other forms of representation. The study suggested that

the choices students made when determining which form of representation to use was based on the classroom techniques the teacher used most often; one method of representation was often used exclusively when solving one particular type of algebraic inequality rather than using various methods (Tsamir & Almog). The authors further suggested that teachers are not representing inequalities to the students in a visual way as often as they might should, especially with the growing availability of graphing calculators. Blanco and Garrote (2007) agreed that students' learning was enhanced when they were introduced to various methods to solve inequalities. The different strategies also helped a greater number of students understand the concept of inequalities. Students may have avoided many of the mistakes made using the algebraic strategy if they were able to see a visual representation of the solution and evaluate its reasonableness. To be able to accurately understand and correct these misconceptions about inequalities held by students, teachers must know how to represent inequalities in various ways.

Teachers also should be aware of the intuitive misconceptions students have about inequalities (Tsamir & Bazzini, 2004). Tsamir and Bazzini conducted a study of 148 high-school students in high-level mathematics courses. All students were given a questionnaire and 21 were selected to interview privately regarding their answers. The researchers concluded that the participants held two intuitive beliefs: the solving process for inequalities and equations is the same and solutions to inequalities cannot be equations but must also be an inequality. To help overcome these wrong intuitions, the Tsamir and Bazzini suggest that teachers be constantly aware of the misconceptions students have and promote student awareness of their misconceptions. However, teachers themselves must be free from misconceptions about inequalities and have a deep understanding of mathematical knowledge or they will lack the insight needed to identify, interpret, and respond to students' misconceptions (Ball, Lubienski & Mewborn, 2001).

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Constructing Elementary Teachers' Beliefs, Attitudes, and Practical Knowledge Through an Inquiry-Based Elementary Science Course

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This study examines inservice elementary school teachers' beliefs, attitudes, and practical knowledge toward inquiry-based science instruction and the influence of an inquiry-based elementary science course on teachers' beliefs, attitudes, and practical knowledge regarding inquiry. Both surveys and a case study were administered to the 14 elementary school teachers before and after completing a three-credit elementary science methods course that was inquiry-based. The findings showed that the teachers' beliefs, attitudes, and practical knowledge about inquiry were clearly influenced by the course. Through this course, the teachers developed fairly positive beliefs and attitudes that promoted inquiry instruction. The majority of participants also improved their knowledge and skills of conducting inquiry as they successfully practiced inquiry-instruction in their science teachings.

Recent science education reforms call for an innovative instructional design based on inquiry that engages K-12 students, allowing them to make meaningful constructions of scientific concepts. These reform documents include *Science for All Americans* (American Association for the Advancement of Science [AAAS], 1990), *Benchmarks for Science Literacy* (AAAS, 1993), and *the National Science Education Standards* (National Research Council [NRC], 1996) — all emphasizing the role of inquiry-based science instruction.

Although inquiry-based instruction is recognized as an effective method of teaching and learning science, there has been limited success in implementing this practice in classrooms. Researchers have indicated that teachers' beliefs, attitudes, and practical knowledge are crucial factors in promoting a reform-based curriculum such as inquiry-based science instruction. Wallace and Louden (1992) suggest that the lack of success of reform efforts is attributed to the failure to take into account teachers' beliefs and practices when developing a new curriculum. Teachers use their knowledge base to make decisions on all aspects of teaching and also in adjusting to a new curriculum (Duffee & Aikenhead, 1992). It is, therefore, inevitable that teachers' beliefs, attitudes, and practical knowledge of inquiry have a direct and substantial impact on teaching science as inquiry.

Research literature about teacher education indicates that teachers tend to teach in the manner in which they were taught when they were students (Eiriksson, 1997; NRC, 1996; Phelps & Lee, 2003; Stuart & Thurlow, 2000). Teachers develop views about teaching from their own learning experiences. With this in mind, teacher education courses as well as college educators play a major role in the reform by providing both preservice and/or inservice teachers with meaningful experiences. It is through these experiences that teachers develop their own positive beliefs, attitudes, and knowledge with regard to science teaching.

The primary goal of the current national reform is to promote science teaching and learning for all children (AAAS, 1990; NRC, 1996). This goal implies that K-12 teachers are expected to have the necessary abilities and knowledge to meet the needs of all learners in the regular classroom. In order to make science meaningful for all children, teachers must be capable of responding effectively to the reform that includes learning and teaching science as inquiry- based. Changes in teacher education programs are necessary to ensure that teachers develop understanding and abilities to meet these expectations. In doing so, current reform in science education encourages changes in teacher preparation programs to ensure that teachers adopt an appropriate inquiry-based approach to teaching science.

The purpose of this study is to describe inservice elementary school teachers' beliefs, attitudes, and practical knowledge toward inquiry-based science instruction and to examine the influence of an inquiry-

based elementary science course on teachers' beliefs, attitudes, and practical knowledge regarding inquiry. In order to accomplish this goal, the study addressed the following research questions: (1) What are inservice elementary school teachers' beliefs and attitudes toward inquiry-based science teaching prior to taking an inquiry-based elementary science course? (2) To what extent do inservice elementary school teachers demonstrate practical knowledge about inquiry-based science teaching? (3) How are teachers' beliefs, attitudes, and practical knowledge changed by an inquiry-based elementary science course?

Theoretical Framework

While numerous educational theories have explored learning processes, constructivism is very appealing, offering the philosophical basis for various types of practical instructions. In turn constructivism has brought new concepts of learning and teaching to education (Mayer, 2004). It describes how learners attain, develop, and use cognitive processes in order to construct an understanding or knowledge for themselves (Haney & Lumpe, 2003). Constructivist perspectives about learning have been broadly accepted among educators and have served as frameworks for understanding learning and teaching (Airasian & Walsh, 1997). There have been many efforts to translate constructivism into educational practices so that students are able to construct their own knowledge.

There are a number of distinct contributions of constructivism in science education. In the perspectives of constructivism, teachers alter their beliefs about the learning and teaching, and in turn, they focus on student involvement and on understanding as the goal of science instruction (Atwater, 1996; Lordbach & Tobin, 1992; Matthews, 1998). Social constructivism, especially, provided an epistemological basis for researchers regarding inquiry-based science instruction (Keys & Bryan, 2001). Emphasizing social interactions in constructing one's knowledge, constructivism allowed researchers to examine how teachers and students form their beliefs regarding inquiry, how teachers implement inquiry in the local context, and how students use tools during inquiry-based instruction (Eick & Reed, 2002).

In addition, constructivism has a very appealing assumption: that all students can learn (Airasian & Walsh, 1997). The *Standards* and *Science for All Americans* of Project 2061 endorsed a constructivist perspective in this regard (Haney & Lumpe, 2003).

Definition of Inquiry-Based Science Instruction

Inquiry has been a perennial and central term in science education reforms in the United States (Abd-El-Khalick et al., 2004). The term "teaching science as inquiry" has been frequently used in many different ways including doing science, hands-on science, discovery learning, project-based learning and real-world science (Crawford, 2000). As it was used in many terms, inquiry was ambiguously defined sometimes as a way to teach science or a method for addressing all important educational goals.

However, in 2000, Crawford pointed out that the term "inquiry" should not be equated with the terms "hands-on science" or "discovery learning," in which a series of hands-on activities are provided, often without science content. Defining inquiry as hands-on activities alone results in clueless learning (Mayer, 2004) and consequently it does not guarantee meaningfulness (AAAS, 1993).

While many researchers have examined the definition of inquiry, it was the *National Science Education Standards* (NRC, 1996) that presented the concept of inquiry-based science instruction which reflects upon the current consensus among the science education community. The NSES refers to inquiry as an instructional approach that helps K-12 students develop an understanding of scientific knowledge as well as skills to conduct inquiry. These skills include identifying and posing scientific questions, designing and conducting investigations to answer the question, analyzing data to construct explanations, and communicating the findings (NRC, 1996, 2000). In sum, the NSES are explicit about the dual roles of inquiry that cultivate the content and process in science education.

A Relationship among Teachers' Beliefs, Attitudes, and Practical Knowledge

Attitude represents an individual's metal position to like or dislike an object (Barros & Elia, 1998). People's beliefs about an object have a predictable influence on their attitudes; thus, people construct their attitudes on the basis of their beliefs (Albarracin & Wyer, 2005). Teachers' beliefs are defined as a repertoire of general knowledge of objects, people, events, and their characteristic relationships (Fang, 1996). A belief system plays a key role in the process of creating and recreating practical knowledge (Pajares, 1992). Beattie (1995) defines practical knowledge as teachers' experiential knowledge of a repertoire of instructional

techniques, classroom management skills, and students' learning needs. In the classroom, teachers' beliefs influence their attitudes and practical knowledge and consequently their teaching practice (Barros & Elia, 1998).

Nespor (1987) suggests teachers' beliefs about teaching are constructed through their experiences as students first, and later they transmit their beliefs into their own teaching patterns. The types of belief systems teachers have depend on their personal histories, experiences with family and also from learning in and out of school. These personal beliefs are powerful factors, influencing teachers' pedagogical thinking (Helms, 1998; Knowles & Holt-Reynolds, 1991). As a result, teachers develop strong sets of personal beliefs regarding plans and teaching practices based on their personal experiences (Clark & Peterson, 1986; Sulman, 2006). These personal beliefs of teachers give rise to the various teaching methods, despite similar teaching context, curriculum, and degree of subject knowledge. For example, teachers who believe that knowledge is a set of facts are likely to transmit sets of facts to students (Yerrick, Parke, & Nugent, 1997). In contrast, teachers who believe in the importance of students' interpretation of knowledge, focus on the process of transformation of knowledge among students.

The school science curriculum, thus, rests upon a body of knowledge and a certain instructional method which teachers choose (Schön, 1987). Although the new reform of science teaching is clearly and comprehensively stated, teachers may not implement it until they hold strong beliefs regarding the new instruction (Yerrick et al., 1997). In this respect, it is inevitable that teachers' beliefs, attitudes, and practical knowledge of inquiry have a direct and substantial impact on implementing inquiry-based science instruction in the classroom.

Practical Importance of Teaching Science as Inquiry in the Elementary Level

A number of scholars are concerned about science education in the elementary schools (Appleton & Kindt, 2002; Goldston, 2005; King, Shumow, & Lietz, 2001; Sivertsen, 1993). These scholars believe that many elementary students across the United States receive inadequate science education. Goldston clearly stresses, "It is important to recall that science in the elementary grades is being left behind" (p. 186). To improve elementary science education, a new approach to the teaching of science is needed in order to engage students to consistently and meaningfully construct knowledge through application (Anderson, 1997; Brandwein, 1962).

While recent science reform is nurturing a fundamental goal, meaningful science learning for all children, a growing number of researchers widely recognize the need to better prepare teachers to accomplish this goal (Gess-Newsome, Southerland, Johnson, & Woodbury, 2003; NRC, 1996; Stuart & Thurlow, 2000; Watters & Ginns, 2000; Weld & Funk, 2005). They note that science education of teachers is a critical component in making real change, and in turn, securing lasting reform in the classrooms. For this reason, it is necessary to bring a systemic change to teacher preparation courses and also to the faculty's method of delivery (Cuban, 1988).

To improve science education in elementary schools, educators and researchers applied a twofold approach: implementing inquiry-based science instruction in elementary schools and also developing new teacher education programs that are specially designed with inquiry-oriented pedagogy. In doing so, it is expected that teachers' levels of science content knowledge and skills are strengthened as a result of exposure to inquiry-based programs, with the result that students are provided adequate learning environments and experience diverse ways to develop the abilities and understandings of scientific inquiry, as well as the understanding of the fundamental subject knowledge of science (Bybee, 2000; NRC, 1996).

Methodology

This study, constructed from a constructivist perspective, examined inservice elementary school teachers' beliefs, attitudes, and practical knowledge toward inquiry-based science instruction and the influence of an inquiry-based elementary science course on teachers' beliefs, attitudes, and practical knowledge regarding inquiry.

Participants

The participants in the study were 14 inservice elementary school teachers enrolled in a three-hour, elementary science methods course that emphasizes teaching science as inquiry at a large urban university in the spring of 2007. All participants volunteered to participate in the research. All of the participants except one were women. Among the 14 teachers, eight were elementary education majors and six were education majors of other content areas (e.g., English, history, natural science, and physical education). All teachers were certified elementary school teachers and

currently enrolled in a Master degree program. The teachers had a broad range of years of teaching experience: two teachers had taught 0-3 years; two 4-6 years; three 7-10 years; four 11-15 years; and three 16-20 years. Participants had completed a wide range of science coursework during their undergraduate studies; nine teachers had 0-3 courses; three had 4-7 courses; and two had more than 10 courses.

Elementary Science Course

The course structure incorporated two major conceptual frameworks. One was the learning philosophy, derived from a constructivist idea of teaching and learning. The other was a model for inquiry-based and learner-centered instructional strategies. The participant teachers worked in a small group setting seated around tables in groups of four or five. They were encouraged to collaborate within their small groups while they investigated problems or tasks.

This course was aimed at enabling the elementary school teachers to plan and implement effective and appropriate science instruction based on principles of the *National Science Education Standards* (NRC, 1996). Table 1 shows the overview of the course. The course consisted of three phases. During the first phase, participants explored the concepts of the nature of science and inquiry-based science teaching through reading materials and extensive discussions. After giving participant teachers the opportunity to build a conceptual understanding of inquiry-based science instruction, the teachers were subsequently engaged in inquiry-based activities during the second phase.

In the final third phase, participants created their own inquiry-based science lesson, applying their knowledge and understanding of the inquiry-based instruction. Each participant prepared and taught a 30-minute elementary-level science lesson to the class. Additionally, participant teachers completed an experimental journal of critter observations, essays, science lesson plans, and presentations. The goal of these assessments was to measure participants' learning through opportunities for them to share their understanding and reflections of inquiry-instruction.

Data Collection and Analysis

Both quantitative and qualitative data were collected. Qualitative data were collected through semi-structured interviews, practice teaching observations, students' lesson plans, and written reflections of the participants. The interviews were tape-recorded, and

Table 1
Outline of the Elementary Science Course

Phase	Theme	Day	Activities
I	▪ Overview of conceptual framework:	1	Invisible letter What is on your cubic box?
	– Nature of Science – Constructivism – Inquiry-Instruction	2	Begin with long-term investigation, watching critters Reading and discussion with science journals
II	•Inquiry-based lessons to develop:	3	School Science Safety Learning Cycle (5E Model)
	– Science Process Skills	4	Floating raisins experiment Jumping frogs
	– Science Concepts (Physical Science, Earth Science, Life Science)	5	Oreo investigation
		6	Paper helicopter
		7	Swinging a pendulum
		8	The Lorax: Cause and effect
		9	Lighting shoes: Electronic circuit
		10	Life cycles
III	•Students' practice teaching	11 – 13	Each student designs and presents a 30-minute science lesson to the class
		14	Collaborative revision of the lesson
		15	Critter-log presentation Review of the course

the construction of the interview items followed techniques and procedures published in previous studies (Atwater, 1996; King et al., 2001; Zacharia, 2003). The interview protocol consisted of four categories: prior knowledge, belief, practical knowledge, and practice.

Practice teaching observations for each participant were measured using the Reformed Teaching Observation Protocol (RTOP), designed by the Evaluation Facilitation Group of the Arizona Collaborative for Excellence in the Preparation of Teachers (Sawada et al., 2002). RTOP was a twenty-five-item classroom observation protocol that includes five subscales. The score resulted in an individual practice teaching ranging from 0 – 100 describing the degree of inquiry-reform present. Any RTOP score greater than 50 indicated considerable presence of "inquiry-reformed teaching" in a lesson. The reliability was estimated by Cronbach's alpha 0.97 for the 26 items and ranging from 0.80 to 0.93 for subscales. Validity correlation coefficients ranged from 0.88 to 0.97.

Quantitative data were obtained using a 22-item Likert scale of the Revised Science Attitude Scale (Bitner, 1994; Thompson & Shrigley, 1986). The survey was administrated for measuring participants' attitudes, and to all participants at the beginning and end of the elementary science course. The reliability estimate, using coefficient alpha, was 0.89 and validity coefficient ranged from 0.46 to 0.70 (Bitner; Thompson & Shrigley).

To examine the participants' responses to the survey, percentages of disagreement, agreement, and neutral were calculated for the small size of participants (N = 14). A constant comparative method and triangulation (Strauss & Glaser, 1980) were used for analyzing the qualitative data. Analysis of the data using the constant comparison method enables the examination of relationships among the participants' beliefs, practice patterns, and assertions (Watters & Ginns, 2000). A four-step procedure that includes chunking, defining and integrating categories, and reliability check used for the study was modified from Bohning and Hale (1998), Merriam (1998), Miles and Huberman (1994), and Strauss and Glaser (1980).

During the analysis, all data were chunked into one or three sentence statements representing a single idea, and then the chunked data were clarified into coding categories. At this point, the most common patterns and a summary are made of the categories for each participant's case and all patterns are then incorporated into narratives of individual profiles. All steps were checked for consistency by three trained researchers. Interview transcripts, lesson plans, and reflective notes were typed into computer word-processing files for the analysis. Establishing inter-rater agreement for the qualitative data, both percent agreement (Miles & Huberman, 1994) and Cohen's kappa coefficient (DeVellis, 2003; Miller & Worthington, 2007) were calculated. The value for the agreement was 82% and 0.763 for the kappa coefficient.

Findings

Beliefs and Attitudes

Most of the participant teachers did not hold any beliefs about inquiry-based science instruction, responding that they were not taught this way before taking the course (Figure 1). Only four teachers (29%) shared their beliefs about inquiry-based science instruction. They viewed inquiry-based science as asking questions, providing hands-on activities, and having a student-centered approach to learning. After completing the course, all of the 14 teachers constructed or expanded their beliefs on inquiry instruction, becoming more aware that it involved student-centered, open-ended exploration, and a deeper understanding of concepts that ultimately led to meaningful learning of science.

Participants' attitudes on inquiry-based science instruction are summarized in Table 2. From the results of the pretest, most of the participants had positive attitudes to the importance of science teaching in elementary level (12 of 14, 85.7%) and toward learning and teaching science content and lab through inquiry instruction in general. However, these participants also hold negative attitudes about the actual practice of delivering science in their classrooms, especially using inquiry-instruction. The participants responded that they were reluctant (12 of 14, 85.7%), even dread (11 of 14, 78.6%) to teach science because they believe they have a shortage of knowledge and skills (10 of 14, 71.4%) required to teach science and practice inquiry-based science instruction.

After the completion of the course, all participants responded they no longer dreaded employing an inquiry approach, and only one teacher differed from the others in not being comfortable with teaching inquiry-based science. More teachers (78.3%, 11 of 14) agreed on enjoying the use of science equipment and planning inquiry-instruction. However, these participants' attitudes towards actual usage of inquiry instruction in their teaching still remained negative and this result

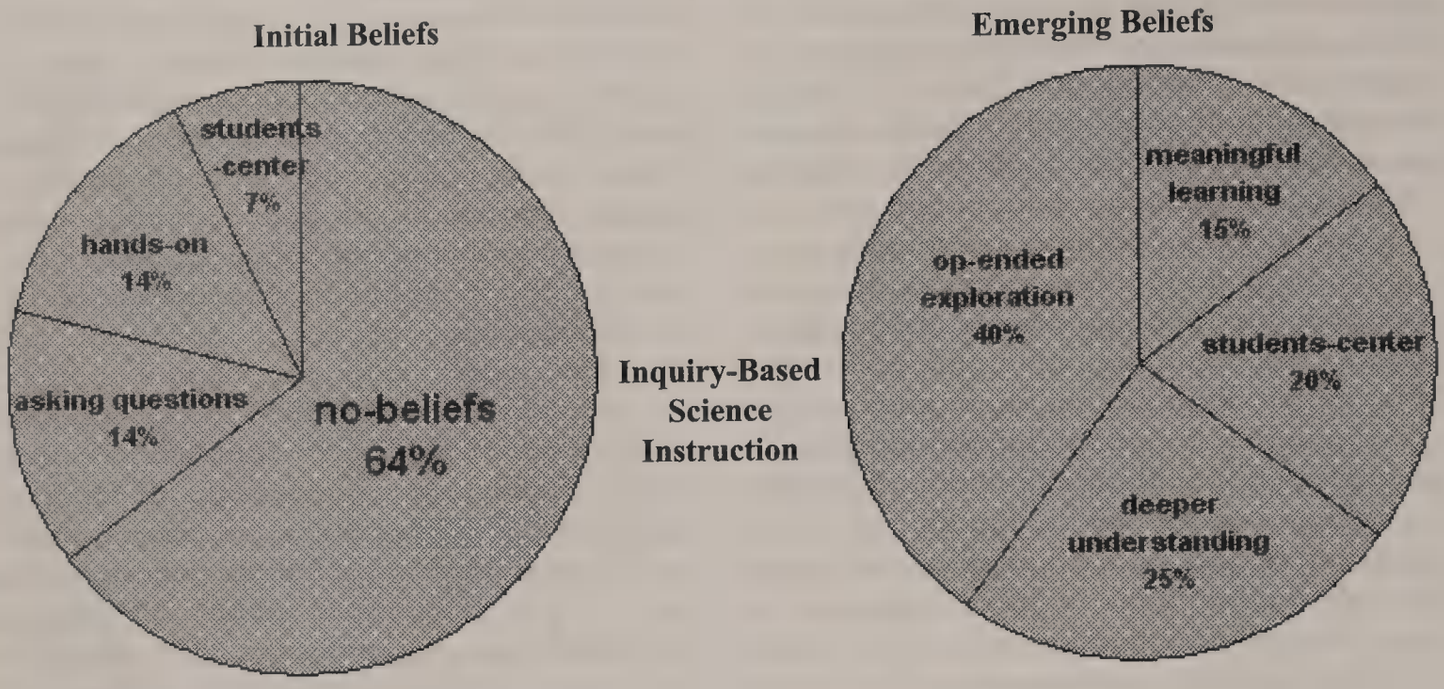

Figure 1. Changes in participants' beliefs.

was consistent with their shared negative attitudes with regard to their shortage of knowledge necessary to teach inquiry and inquiry instruction is time consuming.

Practical Knowledge

The mean score of RTOP for the teachers was 55 and ranged from 76 to 33. Eight teachers (57%) achieved RTOP scores greater than 50, representing the presence of inquiry teaching in their lessons (Table 3). Sub-totals for each sub-category were also analyzed to assess participant teachers' strengths and weaknesses in regard to inquiry instruction. The sub-categories with the highest mean scores were classroom culture-teacher and students' relationship with 14.4 out of 20, and the lowest mean score was for content-procedural knowledge, with 7.7 out of 20.

Based on the participant interviews, the teachers valued inquiry-based instruction and believed teaching science as inquiry in the elementary classroom was beneficial in engaging students with open-ended explorations, improving students' involvements, increasing a deeper understanding, and connecting to the students' prior knowledge (Table 4). They also identified some of the disadvantages of inquiry-instruction, including requiring too much time and materials, difficulties of assessing, and making little connection with concepts.

While taking the course, 12 teachers (86%) tried to implement inquiry-based science lessons in their classrooms. The frequency of using inquiry instruction in the classroom varied among the teachers from all the time to at least one time per month. Two teachers reported that they did not provide any type of inquiry-lessons to their students because they believed that planning and delivering inquiry lessons require too much time and effort.

Discussion

The majority of the elementary school teachers in this study did not have any beliefs about inquiry-based science instruction due to their lack of exposure to and experience with this type of pedagogy prior to this course, including high school education, undergraduate programs, and professional development programs. According to recent research (King et al., 2001; Loucks-Horsley & Mattsumoto, 1999), a high proportion of teachers are inadequately prepared during undergraduate programs, both in terms of science content and instructional skills. Consequently, teachers often lack the support network that they need to facilitate their teaching using an inquiry-based approach (Eick & Reed, 2002). In this study, only a few teachers experienced some degree of inquiry-instruction and these experiences enabled them to perceive positive beliefs on inquiry instruction.

After completing the course, there were some positive changes in participants' attitudes toward learning and teaching science content and lab through inquiry-instruction, Related to this result, other researchers reported that well-designed inquiry programs influenced a change in teachers' beliefs, attitudes, and self-efficacy, including: a science professional development

Table 2
Attitudes of Participants (Pretest and Posttest Results)

Statements	Surveys	% Disagree (N)	% Agree (N)	% Neutral (N)
1. Comfortable teaching inquiry	Pre	21.2 (3)	78.6 (11)	0.0
	Post	7.1 (1)	78.5 (11)	14.3 (2)
2. Teaching science in elementary is important	Pre	71.1 (1)	85.7 (12)	7.1 (1)
	Post	0.0	100.0 (14)	0.0
3. Fear that unable to teach inquiry	Pre	71.1 (1)	78.5 (10)	21.4 (3)
	Post	71.1 (1)	78.5 (10)	21.4 (3)
4. Inquiry lesson is time-consuming	Pre	14.3 (2)	64.3 (9)	21.4 (3)
	Post	28.5 (4)	64.3 (9)	7.1 (1)
5. Enjoy the lab	Pre	7.1 (1)	42.8 (6)	50.0 (7)
	Post	0.0	85.7 (12)	14.3 (2)
6. Difficult to understand science	Pre	14.3 (2)	64.3 (9)	21.4 (3)
	Post	7.1 (1)	78.6 (11)	14.3 (2)
7. Comfortable with science content	Pre	21.4 (3)	57.1 (8)	21.4 (3)
	Post	7.1 (1)	78.6 (11)	14.3 (2)
8. Interest in working on inquiry-instruction	Pre	7.1 (1)	71.5 (10)	21.4 (3)
	Post	7.1 (1)	92.9 (13)	0.0
9. Dread teaching inquiry-instruction	Pre	14.3 (2)	78.6 (11)	7.1 (1)
	Post	100.0 (14)	0.0 (0)	0.0
10. Not afraid to demonstrate science	Pre	7.1 (1)	78.6 (11)	14.3 (2)
	Post	0.0	92.9 (13)	7.1 (1)
11. Reluctant to teach science	Pre	14.3 (2)	85.7 (12)	0.0
	Post	14.3 (2)	85.7 (12)	0.0
12. Enjoy helping students' with science equipment	Pre	14.3 (2)	85.7 (12)	0.0
	Post	0.0	85.7 (12)	14.3 (2)
13. Willing to spend time to plan inquiry	Pre	7.1 (1)	92.9 (13)	0.0
	Post	0.0	100.0 (14)	0.0
14. Shortage of knowledge to answer students' questions	Pre	28.5 (4)	71.4 (10)	0.0
	Post	14.3 (2)	71.4 (10)	14.3 (2)
15. Science is basic skill to learn	Pre	7.1 (1)	85.7 (12)	7.1 (1)
	Post	0.0	100.0 (14)	0.0
16. Enjoy manipulating science equipments	Pre	14.3 (2)	85.7 (12)	0.0
	Post	0.0	78.6 (11)	21.4 (3)
17. Fear of unexpected event happening during the lab	Pre	7.1 (1)	78.5 (11)	14.3 (2)
	Post	7.1 (1)	64.3 (9)	28.6 (4)
18. Science is my preferred subject to teach	Pre	28.5 (4)	42.9 (6)	28.6 (4)
	Post	21.4 (3)	42.9 (6)	35.6 (5)
19. Expect students' excitement with inquiry-instruction	Pre	0.0	100.0 (14)	0.0
	Post	0.0	100.0 (14)	0.0
20. Too much effort to teach inquiry	Pre	7.1 (1)	85.7 (12)	7.1 (1)
	Post	7.1 (1)	85.7 (12)	7.1 (1)
21. Children are not curious about scientific matters	Pre	0.0	100.0 (14)	0.0
	Post	0.0	100.0 (14)	0.0
22. Plan to investigate science into other areas	Pre	7.1 (1)	92.9 (13)	0.0
	Post	7.1 (1)	92.9 (13)	0.0

Table 3
RTOP Scores of Participants

Participants	RTOP Total Score*	Sub-Categories**				
		Lesson design/ implementation	Content		Classroom culture	
			Propositional knowledge	Procedural knowledge	Communication	Teacher-and-students relationship
P001	33	5	10	3	7	8
P002	50	10	11	8	8	13
P003	44	16	13	1	3	11
P004	45	16	14	1	3	11
P005	75	14	13	12	16	20
P006	76	16	15	14	14	17
P007	64	16	5	9	14	19
P008	63	16	6	9	14	18
P009	54	11	12	7	10	14
P010	62	11	15	9	11	16
P011	52	6	10	9	11	16
P012	69	16	11	15	14	17
P013	44	12	12	6	4	10
P014	43	10	8	5	8	12
M	55	12.5	11.1	7.7	9.8	14.4

* Possible scores 1 ~ 100 and any RTOP Scores < 50 reflect an inquiry-lesson.
** The highest possible score for each sub-category was 20.

program (Lumpe, Haney, & Czerniak, 2000), a hands-on physics laboratory program (Freedman, 1997), and a professional summer workshop (Butts, Koballa, & Elliott, 1997); a science workshop was shown to increase teachers' understanding and positive beliefs about science (Johnson, 2004).

However, the participants' attitudes with regard to being reluctant to teach science and toward fear of teaching inquiry remained in negatively by the end of the course. In order to change teachers' attitudes, their core beliefs must change to allow rationalizing new perspective (Albarracin & Wyer, 2001). Cronin-Jones (1991) also found that teachers have difficulty in incorporating the new perspective, emphasizing values different from those that teachers hold. Changing process in attitudes may take a long period that more than a semester as for this study.

After the completion of the course, most of the teachers implemented inquiry-based instruction in their practice teachings of science. Other teachers also tried to implement some degree of inquiry-based instruction using learning-activities and asking questions in their lessons and none of the teachers used traditional lecture instruction during their lesson. Other research acquired similar results of successful practicing in teaching science as inquiry with specially designed inquiry-summer programs (MacIssac & Falconer, 2002; Ruth, 2007).

On the other hand, the majority of participant teachers exhibited strengths in facilitating students' active participation and they showed weaknesses in using scientific reasoning and an understanding of pedagogy as demonstrated by their sub-categories of RTOP. This finding was consistent with results from other research. Wallace and Louden (1992) suggested that few elementary school teachers have strong content and pedagogical knowledge of science. Other researchers also mentioned that elementary school teachers generally

Table 4
Practical Knowledge of Participants

Question	Reasons (Categories)
Advantages of inquiry	Open-ended exploration Improve student involvement Deeper understanding Connect to prior knowledge
Disadvantages of intuiry	Time-consuming for planning Shortage of materials Difficulty of assessments Little connection to the content
Inquiry usage in their teaching	Practice of inquiry-instruction: Open-ended exploration, students' interests and involvement No-practice of inquiry-instruction: Time-consuming
Frequency of inquiry teaching	All the time: 3 3 & more/week: 4 1/week: 2 1 or 2/month: 3 None: 2 (Time-consuming)
Future use of inquiry	Ownership of learning Student involvement Build solid knowledge Engaging communications
Constraints to implementation	Time-consuming for planning & efforts Shortage of materials
Needs for the implementation	Knowledge & skills to do inquiry Materials Planning time & efforts Collaborative relationships

Note: Source from the participants' interview

have been found to possess a low level of content and procedural knowledge of science (Carol & George, 1996).

Some teachers had difficulty in incorporating inquiry-instruction in their practice teaching. Successful translation of inquiry-instruction in the classroom requires teachers' strong beliefs, knowledge, and expertise to do inquiry (Jeanpierre, Oberhauser, & Freedman, 2005). The majority of these teachers had never been exposed to inquiry-instruction before completing this course and they might need more opportunities other than that described in this study to experience this type of instructional approach in order to practice inquiry instruction in their teaching successfully. On a positive note, after completing the course, the participants expressed that they would continue to use more inquiry-instruction in their classroom.

Results from the RTOP scores and the teachers' beliefs and attitudes suggested that the teachers' beliefs and attitudes could be used to determine the factor that predicts particular teaching patterns. Therefore, if a teacher felt comfortable in teaching science and using inquiry-instruction, then they were likely to carry out inquiry-instruction in their lessons. Roehrig and Luft (2004) proposed that the translation of inquiry-instruction in the classroom requires teachers' supporting beliefs, with prior and current experience. In the classroom, teachers' beliefs influence the whole processes of instructional decisions, including how to translate and utilize the content knowledge they possess, and how to develop their practice (Pajares, 1992). Consequently, this study concluded that the el-

ementary science course influenced the teachers' beliefs and attitudes about inquiry-instruction, and that these beliefs and attitudes affected their decision-making process to favor teaching science as inquiry in their teaching practices.

Implications

In view of the results and conclusions produced by this study, there are two major implications for implementing inquiry-based science instruction in the classroom. First, teachers in this study need more exposure to learning inquiry-based science instruction. Second, beliefs and attitudes towards inquiry-based science instruction of participant teachers may affect the practice of inquiry in teaching science in their classroom.

Therefore, it is recommended that teachers should have more opportunities to provide a rich context of knowledge and experience on inquiry instruction during and after their teacher preparation programs. These teachers, thus, construct positive beliefs and attitudes toward inquiry-based science instruction, which will help them in their efforts to practice this approach in the classroom. Apparently, college teacher-education programs and professional developments are expected to contribute to this effort in developing positive beliefs and attitudes on inquiry-based science instruction. Ultimately, this effort may lead to successful implementation of an inquiry-based reform in K-12 science education.

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Computational Estimation Performance on Whole-Number Multiplication by Third- and Fifth-Grade Chinese Students

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Four hundred and three 3rd- and 5th-grade Chinese students took the Multiplication Estimation Test or participated in the interview on it, designed to assess their computational estimation performance on whole-number multiplication. Students perform better when tasks are presented visually than orally. Third graders tend to use rounding based while fifth graders tend to use written algorithm based strategies, but boys' and girls' performances do not differ. It is concluded that students often will not estimate simply at the request to estimate if an exact answer is within their mental computation capability, and a two-step process is suggested for helping students decide what route to take when given arithmetic problems.

Computational estimation is the process of arriving at a rough but reasonable answer to an arithmetic problem in a relatively quick manner without resorting to any external calculating devices such as paper and pencil. It has been recognized as important both in and outside school. In the former case, it provides important information about students' cognitive development in the domain of mathematical competence (Case & Sowder, 1990) as well as their general understanding of mathematical concepts and relationships (Dowker, 1992). For many students, it is also an important tool in doing schoolwork, such as checking if an answer obtained through precise computation during a test is reasonable. Outside school, it is often called for in place of precise computation. An example of this is estimating the amount of a tip in a restaurant.

The need for emphasizing computational estimation in mathematics curriculum began to be recognized during the early 1980s. For example, the Conference Board of the Mathematical Sciences (1982, p. 4) recommended that "substantially *more* emphasis be placed on the development of skills in mental arithmetic, estimation, and approximation." Since then studies have been conducted on this topic. As an indicator of its recent status in American mathematics curriculum, the standards for number and operations proposed by National Council of Teachers of Mathematics (2000, p. 32) stated that instructional programs from prekindergarten through grade 12 should enable all students to "compute fluently and make reasonable estimates."

Prior Research on Computational Estimation

The primary focus of earlier studies on computational estimation was to identify different processes or strategies in arriving at an estimate. Reys, Rybolt, Bestgen, and Wyatt (1982) identified three processes that good estimators use: reformulation, the process of altering numbers to a more mentally manageable form, such as rounding $31 \times 68 \times 296$ to $30 \times 70 \times 300$, translation, the process of changing the mathematical structure of a problem to a more mentally manageable form, such as translating $8946 + 7712 + 7814$ into 8000×3, and compensation, the process of making adjustments to reflect the change resulting from reformulation or translation, such as adjusting 24000 to 24400 when an estimator felt that 8000×3 might be an underestimate for the problem just mentioned. Levine (1982) studied 89 college students and used an eight-type scheme to classify their estimation strategies: fractions, exponents, rounding both numbers, rounding one number, powers of 10, known numbers, incomplete partial products (quotients), and proceeding algorithmically. Dowker, Flood, Griffiths, Harriss, and Hook (1996) extended this scheme and classified these strategies into two classes: Class 1 techniques that were likely to be taught in school and Class 2 techniques that involved attention to the particular numbers in a problem and/or the relationships between them and implied a flexible adaptation of strategy to problem type without reliance on standard procedures.

Later studies paid attention to problem characteristics that affected estimation performance. For instance, problems in LeFevre, Greenham, and Waheed's (1993) study varied on digit size (one-digit, two-digit, etc.) and adjustment distance, which is the difference between a digit and its nearest ten. For example, 39 is regarded as having a small adjustment distance because the difference between it and its nearest ten, 40, is 1. In contrast, 36 has a large adjustment distance in that the difference between 36 and 40 is 4. The said study

found that participants' accuracy decreased as digit size increased, and that they were more accurate on small- than large-adjustment problems.

The form in which a problem is presented was also studied. An estimation problem can be either a number problem (a problem in computational form devoid of any contextual information) or word problem (one in story form). The findings are mixed in this respect. While some authors found that their participants were more successful with number than word problems (Threadgill-Sowder, 1984), more authors found evidence supporting the opposite (Gliner, 1991; Morgan, 1989; Reys et al., 1991).

Moreover, some studies focused on the characteristics of subjects that affect estimation performance. Reys et al. (1991) found no consistent pattern concerning the performance of boys versus girls at either fifth- or eighth-grade level. A similar result was reported in LeFevre et al. (1993) and Hanson and Hogan (2000). Case and Sowder (1990) included age as an important factor in their neo-Piagetian analysis of estimation of multi-digit sums. They proposed that estimating sums involves two essentially different operations, approximating and mentally computing, and that children are not able to coordinate these two operations until they enter the vectorial stage, around 11 or 12 years of age. Lemaire, Arnaud, and Lecacheur (2004) documented young and older adults' age-related changes in computational estimation performance and in adaptivity of strategy choices.

Research on computational estimation and its related areas has been conducted on participants from other countries as well, such as Australia, Britain, Canada, France, Japan, Mexico, and Taiwan (Dowker, 1997; Lemaire, LeCacheur, & Farioli, 2000; McIntosh, Nohda, Reys, & Reys, 1995; Reys, 1991; Reys et al., 1991; Reys, Reys, Nohda, & Emori, 1995; Shimizu & Ishida, 1994; Yang, 2005, 2007). In general terms, it was recognized that estimation ability is not independent of exact calculation ability, and that many students are, in fact, highly dependent on standard written algorithms in their estimation. It is also interesting that the same estimation strategies appear to be used in all the countries where such studies have been conducted (Siegler & Booth, 2005).

In studies of mental computation, an area related to computational estimation (indeed, a few authors defined the latter through the former. See LeFevre et al. (1993)), some researchers focused on the effect of mode of presentation, i.e., whether a task is presented visually or orally, on participants' performance. McIntosh et al. (1995) found that while it affected American and Australian students' mental computation only marginally, the visual mode produced dramatically better success rates for Japanese students than the oral mode. Reys et al. (1995) found that mode of presentation drastically affected their Japanese participants' mental computation, with visually presented items generally producing higher performance. This finding led the authors to claim that "any meaningful report and discussion of student performance on individual mental computation items must also describe the mode of presentation" (p. 314).

One cannot fail to notice the different languages these participants used. The Japanese language, which uses common Chinese characters, is pictographic and there is no direct relation between how a word is written and how it is pronounced. One will certainly wonder if visually processing a problem caused the Japanese students to perform better than listening to it.

Rationale for the Present Study

Researchers show a sustained interest in mathematics performance of students from other countries, particularly those from China, Japan, Korea and Taiwan (e.g., Fuson & Kwon, 1992; Shen, 2005; Stevenson, Chen, & Lee, 1993). This is because East Asian students consistently outperform their U.S. and European counterparts on international tests of mathematics. This interest suggests that performance by students from other countries has potential to inform mathematics education in the U.S. and other parts of the world.

Nevertheless, something is apparently missing from this picture. On the one hand, Chinese students' mathematics performance has often been studied, in overall scores as well as specific areas such as base-10 counting and place value understanding, symbolic and abstract thinking, and teaching-, language- and family-related factors (Wang & Lin, 2005). On the other hand, when it comes to computational estimation, while students from other countries are a research focus from time to time, no major studies have been conducted on Chinese students. In fact, little is known about how Chinese students perform estimation tasks and what strategies they use. This missing piece is more obvious when we consider the fact that Chinese students comprise a huge population and, internationally, are among the top performers in mathematics. Research on computational estimation without such students participating would be incomplete.

Computational Estimation in Chinese Mathematics

Curriculum

It is interesting to note that there is a similar pattern with the treatment of computational estimation in the Chinese mathematics curriculum compared with that of the U.S. A close look at the mathematics textbooks used nationwide in China in the early 1990s (People's Education Press, 1989) did not produce a single case of requirement for estimation. Over time, however, changes took place. The Chinese elementary mathematics curriculum compiled in the late 1990s introduced estimation (Xu & Li, 2006) and a more recent version emphasized students' estimation skills (People's Republic of China Ministry of Education, 2000). The content standards for grades 1 through 3 state that "[The student should be able to] conduct estimates in combination with the particular context and explain the estimation process" (People's Republic of China Ministry of Education, n.d., p. 12; this author's translation). In a recently published second-grade mathematics textbook (Qingdao Press, 2005), for example, treatment was given to how to estimate 2×1 (2-digit by 1-digit) or 3×1 multiplication problems. Also, many exercises require students to estimate, as frequently exemplified in such directions as "First make an estimate. Then calculate" (Qingdao Press, 2005).

However, as Chinese mathematics instruction is heavily influenced by high school and college entrance examinations (Yan, 1996), estimation in reality has only received scant coverage in classrooms simply because estimation is not tested in such examinations. Xu and Li (2006) searched high school entrance examinations used in 30 provinces in 2004 but did not find any items that would directly test estimation abilities. Their study also revealed that when teachers did touch on estimation, the strategy taught was primarily rounding. For example, in elementary mathematics textbooks used in Zhejiang province, the section devoted to estimation only included the strategy of rounding to the nearest tens or hundreds and then computing.

In summary, while Chinese students' general mathematics performance has been given adequate research attention, no major studies have been conducted on their computational estimation performance. We know little about how they perform estimation tasks, what strategies they use, and whether factors such as the mode of presentation affect their performance. Hence the rationale for the present study.

Overview of the Present Study

The purpose of this study was to collect baseline data for computational estimation by Chinese students. Specifically, this study was driven by the following research questions:

1. Will mode of presentation affect Chinese students' performance in computational estimation?
2. Will characteristics of students, such as gender and grade level, affect Chinese students' performance in computational estimation?
3. Will characteristics of problems, such as digit size, adjustment distance and problem form, affect Chinese students' performance in computational estimation?
4. What computational estimation strategies do Chinese students most commonly use?

Method

Participants and Their Schools

A total of 403 third- and fifth-grade students from four public elementary schools in China participated in this study. The first three schools, located in Yantai, Shandong province, in north China, were selected based on school location and student population, two popular indicators of student performance in general. Large schools, mostly located in the inner city, were well supplied and eagerly sought after by upper-class parents. Middle-sized schools were more spread out, with students more likely coming from working class families. Small schools were scattered in rural areas, with students mostly from farming families. One school from each category was selected, and they had a student population of about 1670, 940, and 350, respectively. The fourth school, a large one with about

Table 1
Participants' Gender, Age and Grade

Grade	Gender		Age[a]	
	Boys	Girls	*M*	*SD*
3rd ($n = 201$)	108	93	9 years 3.9 months	7.1 months
5th ($n = 202$)	108	94	11 years 3.2 months	6.2 months

[a] Based on 376 participants' reported age.

1420 students, was located in the inner city of Nanjing, Jiangsu province, in south China. The two cities were about 1200 km apart. The selection of different types of schools was mainly for the purpose of making the sample as representative of the Chinese elementary students in general as possible.

This study was conducted towards the end of the school year. All third graders had, by this time, learned all types of addition problems and 2 × 2 multiplication problems. Fifth graders had learned all problem types covered in the instrument (see below). The participants' demographic data are shown in Table 1.

Instrument

The instrument used in this study, the Multiplication Estimation Test (MET), was based on LeFevre et al. (1993), with the following modifications. Four of the original five sets were randomly chosen, with items in the first two sets designated as number problems and those in the other two as word problems. Since the verbal part of the word problems was not provided in the original study, new word problems in Chinese had to be created. Two kinds of word problems, simple and complex, were distinguished. In a simple word problem, both numbers used were relevant to making an estimate, such as "Mrs. Zhao bought 9 boxes of apples. There are 12 apples in each box. About how many apples did Mrs. Zhao buy?" In a complex word problem, there was an extra number irrelevant to making an estimate (e.g., "Every week, Zhang Min's mom deposits 155 *yuan* in her bank account and gives Zhang Min an allowance of 16 *yuan*. About how much money will she deposit in her bank account after 54 weeks?").

In creating such word problems, third-grade mathematics textbooks were consulted. All characters used were shown to two third-grade language arts teachers from two nonparticipating schools. They confirmed

Table 2
Multiplication Estimation Test

Problem	Characteristics	Problem	Characteristics
1. 9 × 191	N, S, 1	17. 44 × 45	N, L, M
2. 9 × 12	w, S, 1	18. 44 × 136	w, L, M
3. 5 × 156	W, L, 1	19. 6 × 155	w, L, 1
4. 8 × 92	W, S, 1	20. 78 × 189	w, S, M
5. 54 × 56	w, L, M	21. 89 × 121	N, S, M
6. 5 × 144	N, L, 1	22. 8 × 179	w, S, 1
7. 5 × 44	w, L, 1	23. 8 × 112	N, S, 1
8. 12 × 82	N, S, M	24. 4 × 35	N, L, 1
9. 54 × 155	W, L, M	25. 4 × 45	W, L, 1
10. 9 × 78	N, S, 1	26. 9 × 119	W, S, 1
11. 22 × 91	N, S, M	27. 11 × 18	w, S, M
12. 6 × 146	N, L, 1	28. 8 × 18	N, S, 1
13. 5 × 54	N, L, 1	29. 45 × 164	N, L, M
14. 88 × 91	W, S, M	30. 55 × 135	N, L, M
15. 11 × 112	N, S, M	31. 36 × 55	N, L, M
16. 46 × 64	W, L, M	32. 22 × 181	W, S, M

Note. First letter under "Characteristics" denotes problem form: N = Number Problem, W = Complex Word Problem, w = Simple Word Problem. Second letter denotes adjustment distance: S = Small, L = Large. Third letter/number denotes digit size: 1 = Single-digit, M = Multi-digit.

that regular third-grade students had learned all those characters.

The revised MET, consisting of 32 items, had an equal number of problems on all the dimensions it varied on: 16 number problems and 16 word problems (of the latter, 8 simple and 8 complex); 16 with a large adjustment distance and 16 with a small one; and 8 each on the four digit size combinations: 1 × 2, 1 × 3, 2 × 2, and 2 × 3. To prevent a possible practice effect, the order in which the 32 items were presented was randomized (see Table 2. The verbal part of the word problems was stripped).

Procedure

The administration of MET consisted of two components:

1) Class-wide test. At each school, one 3rd- and one 5th-grade class were randomly selected, and participants in each class were randomly divided into two groups of about the same size. One group took the printed form of MET (visual group). No time limit was set for this group, and most participants finished within 30 min. The other group (oral group) went to a separate room, where the investigator read aloud the same items to the participants. An answer sheet with 32 blanks was provided to all participants, who were instructed to estimate, and not line up numbers to calculate, and write estimates in the corresponding blanks. A total of 368 students participated in the class-wide test.

Given the nature of administering a test orally to 20 or 30 students simultaneously, it would be difficult to ascertain that every participant finished an item before the next one was to be presented. Thus, a balance should be struck between not giving sufficient time such that participants would feel under time pressure and giving too much time that it would be possible for participants to use this extra time to calculate exact answers with standard written algorithms. Reys et al.'s (1995) study on mental computation employed a response time of 20 s for two times for each item. However, as computational estimation was supposed to be rough and quick, a shorter response time would be more appropriate. Hanson and Hogan (2000) used a 10-s response time for their college student participants. The pilot study for the present study showed that reading an item two times with a response time of about 10 s for number problems and 15 s for word problems, with a brief pause of about 2-3 s in between, was adequate. This time scheme was adopted.

2) Interview. On each school site, another third- and another fifth-grade class were randomly selected and class rosters obtained. Four students were randomly selected (with the exception of the school in Nanjing, where six students were selected) from each class and individually interviewed. The interview, which was audiotaped, was on Items 1, 6, 8, 15, 24, 28, 29, and 31, all number problems (they were the items of set 1 from the original instrument). Each item, printed horizontally in regular Times New Roman, 36 points, on a 7.6 × 12.7 cm index card, was placed in front of each participant, who was asked to give an estimate and then explain how he or she got that estimate. A total of 35 students participated in this interview.

Criterion for Judging Reasonableness

In analyzing data involving estimates, an important issue is how to judge their reasonableness, as estimates are usually off from their corresponding exact answers by a certain amount. A balance should be struck between being so stringent as to exclude those fairly reasonable answers and being so lenient as to include those that are way off. In defining the appropriateness of an estimation strategy, Dowker et al. (1996) used a cutoff score of 20%. Levine (1982) awarded 3, 2, or 1 point if the score was within 10%, 20%, or 30%, respectively, of the exact answer. While going through the raw data of the present study, this author found that a more lenient criterion should be adopted in order not to exclude estimates by participants using what they considered a legitimate strategy. For 8 × 18, some participants rounded both factors up (to 10 × 20) and got 200, about 39% off. In view of this, a cutoff score of 40% was chosen. For example, if the exact answer of a problem was 100, any estimate between 60 and 140 would be regarded as reasonable and would be scored correct for 1 point. The highest possible reasonableness score was 32 for participants taking the class-wide test and 8 for participants taking the interview.

Moreover, an "exact answer score" was calculated for each participant where 1 point was awarded for each exact answer obtained. This score was used to assess participants' use of written algorithms. The rationale was that resorting to written algorithms usually produces an exact answer while other strategies do not.

Scheme for Categorizing Estimation of Whole-Number Multiplication Problems

Reys et al.'s (1982) three key processes and Levine's (1982) eight types of strategies are fine, useful schemes for categorizing estimation strategies. Yet, these processes and strategies may not be a suitable framework for studying elementary students' estimation performance on whole-number multiplication, for two

reasons. First, they were based on observations of older students and adults (college students or even "pure" mathematicians). Second, the instruments used consisted of several different number types, including decimals and fractions, and other basic operations than multiplication as well. Considering that elementary students would use a narrower range of strategies, this study adopted a three-type scheme to categorize participants' estimation strategies:

1. Written algorithm based—mentally computing an exact answer using written algorithms.

2. Rounding based—"round and multiply" (e.g., rounding 12 and 82 to their nearest tens and then multiplying the rounded numbers).

3. Mathematical property based—using the distributive property ($8 \times 18 = 8 \times 10 + 8 \times 8$) or factorization ($5 \times 144 = 10 \times 144 \div 2$). Although such strategies may also lead to an exact answer, they were not written algorithm based.

Results

Class-wide test

Cronbach's *alpha* was conducted on the 32-item reasonableness score. The coefficient *alpha* index of 0.85 indicated a high estimated internal reliability.

To address research question 1 regarding the mode of presentation, an independent samples *t*-test was conducted comparing the mean reasonableness score of the visual group ($M = 26.6$) and oral group ($M = 25.4$). This was found to be statistically significant, $t\,(366) = 2.31$, $p = .021$, $\eta^2 = .02$, indicating that students will perform better when computational estimation tasks are presented visually than orally. Following the claim made by Reys et al. (1995) that discussion of performance on mental computation must also describe the mode of presentation, a similar claim may be made about the necessity of describing the mode of presentation in discussing performance on computational estimation.

Furthermore, the mode of presentation may interact with the characteristics of problems. On five items (Items 3, 4, 9, 20, and 29), the percentage of visual reasonableness scores exceeded that of oral scores by more than 10 points. A close examination of their characteristics revealed that most of these items were complex word problems. This probably indicates that if a complex word problem is presented visually, participants may go back and forth and then decide on what information to use and what to ignore. However, when the same item is presented orally, participants must first store all pieces of information in their memory before they can pick and choose. This may put them at a disadvantage.

On the other hand, Items 5, 16, 17, and 25 were the only ones where participants, on average, performed better orally than visually. All these items had a large adjustment distance and most were multi-digit. This suggests that when problems have a large adjustment distance and multiple digits, the visual group is no longer at an advantage.

To address research question 2 concerning the characteristics of students, a 2 (gender) × 2 (grade) ANOVA was conducted on the mean reasonableness scores. Neither the interaction, $F\,(1, 364) = .25$, *ns.*, nor the main effect of gender, $F\,(1, 364) = .09$, *ns.*, was significant. But the main effect of grade was significant, $F\,(1, 364) = 5.24$, $p = .023$, $\eta^2 = .01$, with a mean of 26.6 for fifth-grade and 25.4 for third-grade participants. This suggests that fifth-grade students will perform better on estimation tasks than their third-grade counterparts, but boys and girls will not differ in their performance.

Analysis of participants' exact scores showed that, of the 32 items used, third graders obtained an exact answer for an average of 1.4 ($SD = 3.6$) items while fifth graders' average was as high as 12.3 ($SD = 10.3$), $t\,(366) = -13.51$, $p = .000$, $\eta^2 = .33$. This suggests that fifth graders, when asked to estimate, will actually mentally compute an exact answer for about half of all the reasonable answers obtained, but the same tendency cannot be said of third graders.

To address research question 3 regarding characteristics of problems, separate *F* tests were performed to examine the effects of digit size, adjustment distance and problem form on participants' reasonableness scores. Digit size had a significant effect. Participants performed better on 1 × 2 problems than on any other digit size and did better on any 1 × 3 or 2 × 2 problems than on 2 × 3 ones, but the means for 1 × 3 and 2 × 2 problems did not significantly differ. Also, performance was better if problems had a small adjustment distance than if they had a large one. Finally, participants had a significantly higher reasonableness score on number problems than on word problems. Table 3 shows the *F*-test results.

Moreover, characteristics of problems affected exact answer scores. An *F*-test was conducted on exact scores as a function of digit size. This was found to be significant, $F\,(3, 1101) = 128.13$, $p = .000$, $\eta^2 = .26$, with a mean of 2.6, 2.0, 1.4, and 0.9 for 1 × 2, 1 × 3, 2

Table 3
F-test Results of Reasonableness Scores by Characteristics of Problems (N = 368)

Variable	*F*	*p*	η^2	*M*	*SD*
Digit size	85.26	.000	.19		
1 × 2				7.1	1.3
1 × 3				6.7	1.5
2 × 2				6.6	1.7
2 × 3				5.6	2.2
Adjustment	34.75	.000	.09		
Small				13.3	2.6
Large				12.7	2.9
Problem Form	72.23	.000	.16		
Number				13.5	2.6
Word				12.6	2.9

Table 4
Problems That Generated the Highest and Lowest Percentages of Exact Answers (in Descending Order of Percentages, N = 368)

Highest		Lowest	
Problem	%	Problem	%
24. 4 × 35	41.0	29. 45 × 164	12.7
13. 5 × 54	40.2	21. 89 × 121	12.7
7. 5 × 44	34.2	18. 44 × 136	12.5
6. 5 × 144	34.2	32. 22 × 181	12.0
25. 4 × 45	32.9	30. 55 × 135	10.6
2. 9 × 12	31.5	16. 46 × 64	10.6
23. 8 × 112	30.1	20. 78 × 189	6.8
28. 8 × 18	29.1	9. 54 × 155	5.2

× 2, and 2 × 3 problems, respectively. Problems containing a single-digit factor generated the largest number of exact answers while 2 × 3 problems the smallest. Table 4 lists eight problems that generated the largest number of exact answers and eight that generated the smallest.

As reasonableness scores were higher on items with a small adjustment distance than those with a large one, exact answer scores were expected to behave in a similar manner. However, a paired samples *t*-test showed an opposite result. Small-adjustment problems generated a lower exact answer score than large-adjustment problems, $t\ (367) = -4.59$, $p = .000$, with a mean of 3.2 ($SD = 4.8$) for small- and 3.6 ($SD = 4.8$) for large-adjustment problems. This may be due to the large magnitude of some small-adjustment numbers, such as 189. Nevertheless, this effect was difficult to discern, as the composition of such numbers may be mixed

Table 5
Frequency of Types of Strategies Used for Interview Items by Grade Level

	Algorithm Based		Rounding Based		Property Based	
Problem	3rd	5th	3rd	5th	3rd	5th
1. 9 × 191	6	7	11	8	0	3
6. 5 × 144	4	11	13	3	0	4
8. 12 × 82	2	6	15	7	0	5
15. 11 × 112	4	9	13	5	0	4
24. 4 × 35	3	12	11	3	2	3
28. 8 × 18	1	12	16	3	0	3
29. 45 × 164	7	8	7	7	2	1
31. 36 × 55	3	6	11	5	3	7
Total	30	71	97	41	7	30
%	10.7	25.4	34.6	14.6	2.5	10.7

Note. Percentages were based on a total of 280 responses.

(e.g., the one's digit has a large magnitude while the ten's digit has a small one, or vice versa). Further analysis was performed on seven 1 × 2 problems. Items 4, 10, and 28 were classified as high-magnitude (two or all three digits were 8 or 9) while Items 7, 13, 24, and 25 were classified as medium-magnitude (all three digits were 4, 5, or 6). A paired samples *t*-test showed that participants had a significantly lower average exact answer score on high-magnitude problems ($M = .25$, $SD = .37$) than on medium-magnitude problems ($M = .36$, $SD = .42$), $t\ (367) = -9.66$, $p = .000$.

Interviews

This component was designed mainly to address research question 4, about what strategies Chinese students use in performing estimation tasks. Table 5 lists the frequency of the types of strategies used for each of the eight interview items.

Several obvious patterns emerged from participants' responses to the interview questions. The first pattern was their use of written algorithm based strategies despite the author's saying of the word "estimate" in the direction for every item being presented. On average, more than one third of all responses were written algorithm based. Some participants claimed that they "used the vertical notation (lining up) in the head", and some others tried to write out the procedure with their index finger on the desk or on the palm of the other hand. Perhaps what one third-grade participant said about how he solved 5 × 144 was typical of this pattern:

> I multiplied 4 by 5, and got 20. (I) wrote down 0 and carried 2. Then I multiplied 4 by 5 and got 20. 20 plus 2 is 22. I wrote down 2. 1 times 5 is 5, plus the 2 carried, I got 7. So the answer is 720.

But such participants would have a difficult time when faced with multi-digit problems, as, by way of written algorithms, any 2 × 2 or 2 × 3 problems would involve multiplying the two digits in the multiplier with the multiplicand separately and then adding the results together. Usually the participants would spend much more time trying to produce an answer (and some failed to produce one) and, during this process, often got their procedures messed up in their head. As one third grader commented after she wrote with her index finger on the desk and still failed to solve 36 × 55: "I first multiplied 55 by 6, and then multiplied 55 by 3. I used a vertical notation. But when I got to the later steps I forgot the previous ones."

The second pattern was the popularity of the rounding based strategy. On average, about one half of the participants used this "round and multiply" strategy for each of the eight items presented. They would first round either one or both of the operands to the nearest ten or hundred and then multiply them to get an esti-

mate. At the risk of over-generalizing, a typical response to the question "How did you get this answer?" may be summarized as, "I regarded 12 as 10, and I regarded 82 as 80. Then I multiplied 80 with 10 and got 800."

The third pattern was that third- and fifth-grade participants differed significantly in their choice of strategies. Third graders tended to use rounding based while fifth graders preferred to use written algorithm or mathematical property based strategies. This is consistent with third graders' low exact answer scores, as multiplication with rounded numbers is unlikely to produce exact answers.

Table 5 also indicates that few third graders used mathematical property based strategies. The reason may be that, compared with their fifth-grade counterparts, they had not been exposed to such properties yet or had not been able to develop understanding of such properties on their own. Furthermore, the preference of different types of strategies is similar with all problems except for Item 29, where the number of third graders using rounding based strategies is much smaller than that for the other items. Further analysis shows that participants had both the lowest reasonableness and exact answer scores on this item. It seems to be the case that a problem with a large adjustment distance and large digit size would be difficult to handle even after rounding, and this increased difficulty forced some third graders to use the written algorithm.

In general, the interview revealed some impressive performance by some, particularly fifth-grade, participants, as exemplified by their use of some mathematical property based strategies. The first strategy that stood out was the use of the distributive property. For example, a fifth grade participant described how he got 1700 for 9×191: "I regarded 191 as 190. I multiplied 9 by 190, which should be 1700…(Describing the process) I regarded 190 as 200. 200 times 9 equals 1800. I then subtracted 9 tens from 1800 and got 1700." In other words, this participant used the distributive property and took advantage of the fact that 190 could be rewritten as $200 - 10$ such that $9 \times 190 = 9 \times (200 - 10) = 9 \times 200 - 9 \times 10 \approx 1800 - 100 = 1700$. Three participants, in particular, used this property extensively for an average of six times on the eight interview items.

Another strategy encountered was the participants' factoring one of the operands. For example, in estimating 4×35, a fifth grader said he found 2×35 first and then doubled the result. Another fifth grader described how he got 7380 (an exact answer) for 45×164: "I factored 45 into 5 and 9. I [first] multiplied 164 by 5. Then I multiplied the result by 9."

Also observed was some participants' giving the boundaries of an expected estimate. This was, rather than a different strategy, a new way of representing the results arrived at. In estimating 45×164, which turned out to be very difficult for many participants, a third-grade participant said, "164 is close to 160, and 45 is between 40 and 50. [I] first multiplied 160 by 40, and got 6400. Then [I] multiplied 160 by 50 and got 8000. So the answer is between 6400 and 8000." In estimating 4×35, a third grader said, "It is greater than 120, but less than 160, [because] 35 is close to both 30 and 40. 4 times 30 is 120. 4 times 40 is 160."

Discussion

The reason that participants perform better when estimation problems are presented visually than orally may be that the visual mode is the more conventional form of instruction (such as visually presenting algorithms on the board and the use of textbooks) and learning (such as written exercises). During the interview when paper and pencils were not available, some participants resorted to using their fingers to write vertical notations on the desk. This may be an indication that students have got into the habit of relying on the visual presentation of information to solve problems, even when they were given estimation tasks where paper and pencils were not supposed to be needed.

While it is not surprising that fifth graders performed better than third graders, the most striking difference between the two grades was actually their preference of different strategies. Whereas third graders preferred to first round and then find a ballpark figure, fifth graders were more likely to apply written algorithms mentally to find an exact answer. This is consistent with previous findings that students' exact-answer solutions increase with age and estimation skill (LeFevre et al., 1993).

Why was there such a difference between grade levels? One explanation may be that third graders have not learned much about multiplication procedures or acquired the proficiency in handling them. Thus, their predominant strategy is first simplifying a 2- or 3-digit operand into one containing only one significant digit plus one or more zeros (for example, simplifying 191 into 200) and then multiplying the significant digits before attaching the zeros. In contrast, fifth graders have gained sufficient computational proficiency to carry

out a multiplication procedure mentally. This proficiency may make them reluctant to settle for an inexact answer. This reluctance was manifest in the responses several fifth-grade participants gave when asked to estimate a 1 × 2 problem. For example, when presented with 4 × 35, a fifth grader asked, "May I compute an exact answer?" Another fifth grader, when presented with the same problem, felt a little puzzled, "Estimate *this* problem?" He seemed to have the mentality that "when this problem can be easily solved mentally for the exact answer, what's the reason for asking for an estimate?" Still another a fifth-grader, after delineating how he used the written algorithm to get an exact answer for 8 × 18, commented, "This is really easy to mentally compute."

Thus, it is perhaps not the high level of aversion to estimating, as summarized in Hanson and Hogan (2000) and claimed to be not unusual, among fifth-grade participants in their attempts to obtain exact answers. Rather, they simply are more proficient in engaging in mental computation and can handle multiplication problems more with ease than their third-grade counterparts. Their better performance, in fact, relied more on their mental computation skills rather than estimation abilities.

While results concerning the effect of digit size and adjustment distance on reasonableness scores were very much expected (i.e., performance on single-digit or small-adjustment problems better than that on multi-digit or large-adjustment ones), the different performance level between number and word problems is worth noting. Contrary to the finding in some earlier studies that number problems were more difficult than word problems, mean reasonableness scores on number problems in this study were significantly higher than those on word problems. One reason may be that, whereas all number problems contained two numbers, complex word problems contained an extra one. This extra number may have impacted the participants' performance. Also, the medium used in the aforementioned studies was English while the word problems in the current study were in Chinese. As Chinese is a pictographic language where each character has to be learned individually and there is no direct relation between a character's written form and its pronunciation, processing word problems in Chinese may be different from processing a similar problem in English. Further studies where such a variable is controlled are suggested.

Another unexpected finding in this study is that exact answer scores were lower when problems had a small-adjustment distance than those with a large one. The reason may be that, despite their small-adjustment distance, some such numbers had a large magnitude, such as those ending in 8 or 9, and they may be more difficult to mentally compute. For example, although 9 × 78 (Item 10) was classified as a small-adjustment problem, it may be more difficult than a large-adjustment one such as 4 × 35. In fact, the percentage of all participants who correctly computed an exact answer for the former problem was only about half as much as that for the latter (22.0% vs. 41.0%).

This small-adjustment (but probably with a large magnitude), lower-exact-answer-score phenomenon, in fact, may be readily explained with "problem-size effect," which states that in solving arithmetic problems, reaction times and errors increase (namely, become more difficult) with the size of the operands, for example, 9 + 7 is more difficult than 2 + 3 and 6 × 9 is more difficult than 2 × 6 (Zbrodoff, 1995; Zbrodoff & Logan, 2005). Although prior studies on problem-size effect have focused on computation of single-digit addition and multiplication problems, results from the comparison of high-magnitude and mid-magnitude problems from the present study indicate that the same rule seems to apply to multi-digit multiplication problems as well. This may suggest that the current system of classifying estimation problems based on digit size, adjustment distance, and problem form is incomplete. It should at least take on the magnitude of all digits involved. Further studies in this respect are suggested.

Still, it is impressive that some participants in this study could use mathematical property based strategies, such as the distributive property and factorization, at ease. In general, such performance was not likely by participants who resorted to either written algorithm or rounding based strategies, both termed as Class 1 strategies by Dowker et al. (1996). Instead, these were participants who seemed to have a good understanding of some mathematical properties and could use what Dowker et al. termed as Class 2 strategies at ease. Such strategy use has been observed in college students and professionals such as mathematicians and accountants (Dowker et al.; Levine, 1982), but not very often in elementary students. Such performance deserves more research attention.

Conclusions and Implications

What will Chinese students do when asked to estimate a whole-number multiplication problem? Judging

from the data collected from this study, it may be inferred that they tend to either round and multiply or use written algorithms to obtain an exact answer. Students from each group have their own characteristics and contribute differently to our understanding of their performance.

The rounding based group is more likely to consist of third graders than fifth graders. In fact, rounding was the single most commonly used strategy observed among third graders. Usually they are not very concerned about the error incurred during this round-and-multiply process, which can be supported by the fact that few participants used compensation to make their estimates closer after rounding.

Moreover, this round-and-multiply strategy may not be the most efficient for all types of problems, such as those with multiple digits or a large adjustment distance. For example, participants spent considerably more time on 45 × 164 than on any other interview items, even with either or both operands rounded.

Considering that written algorithm based strategies are mental computation rather than estimation strategies, this round-and-multiply strategy was left as almost an exclusive estimation strategy used. One explanation for this overreliance on rounding may be that it was probably the only one taught, and students may not have had opportunities to develop their own. More than a few participants, while explaining how they arrived at an estimate, said, "Our teacher tells us to round down if the digit is 4 or lower and round up if it's 5 or higher." This coincides with the finding by Xu and Li (2006), who quoted Chinese elementary teachers as saying that the primary strategy they taught was *sishewuru* (four-down-five-up).

This extensive use of rounding may have several instructional implications. Students need to be made aware that there are more estimation strategies available than just rounding and that, more importantly, what specific strategy to use needs to be determined in conjunction with the characteristics of the problem at hand. There are perhaps no "one-fits-all" estimation strategies. Students also need to be provided with opportunities to develop their own strategies instead of just being taught one or two commonly used ones, as most good estimators attribute their success in estimation to skills and techniques they develop on their own (Reys et al., 1991).

The written algorithm based group, on the other hand, is more likely to consist of fifth graders. They are more proficient in mentally applying mathematical procedures and, consistent with Reys et al.'s (1991) findings about Japanese students, are reluctant to settle for an inexact answer when the digit size and adjustment distance are within their ability to handle.

This brings up an important issue: Students often will not estimate simply at the request to estimate if an exact answer is within their mental computation capability. In view of this, instruction on computational estimation skills probably should include teaching students how to decide up front what route to take. This is especially important for those who have the ability to mentally compute an exact answer. Instead of asking students to estimate, teachers may lead them in practicing a two-step process:

1. Need assessment: "Is an exact answer needed?"

2a. If yes: Decide on what devices to use: paper/pencil, calculator, or mental computation. Estimation should be incorporated at this stage to check the reasonableness of the answer obtained.

2b. If no:

2b (i). The problem may be too easy not to obtain an exact answer mentally, such as the 4 × 35 problem used in this study.

2b (ii). Estimate. Decide on what estimation strategy to use based on the characteristics of the problem at hand.

Presently most students will simply proceed to 2a without going through a need assessment when given an arithmetic problem. Since most of the mathematics they do on a daily basis is exact-answer oriented, they automatically assume that an exact answer is what they need to arrive at. This explains why many participants in the present study would mentally compute an exact answer in spite of the author's request for an estimate.

Despite this blurring of an exact answer and estimate, the Chinese students' performance on whole number multiplication was very impressive, with a mean reasonableness score of 26.0 (SD = 5.1) for all participants. This could be perceived in two ways. First, most Chinese students displayed a good understanding of what estimation was and could use, albeit only a few, strategies to estimate multiplication problems. This is in sharp contrast with what prior studies have found. For example, in LeFevre et al.'s (1993) study, fourth-grade Canadian students did not appear to understand what estimation was or know how to estimate multiplication problems. Reys et al. (1991) reported that many of their Japanese participants did not understand what they were supposed to do when asked to estimate. Even most of the Taiwanese pre-service

teachers in Yang's (2007) study did not understand what estimation was.

Second, Case and Sowder (1990) proposed that children are not able to estimate multi-digit sums until they reach 11 or 12 years of age. Results from the current investigation did not seem to lend support to this proposition. The third-grade participants in this study, on average, were barely 9 years 4 months old, but they were able to not only estimate multi-digit multiplication problems, but also manage to get most of their answers within a reasonable range, even though multi-digit products are more difficult than multi-digit sums ("Multiplication is repeated addition," as many schoolteachers say – All children have to learn addition before learning multiplication). Apparently, Case and Sowder underestimated children's development of computational estimation abilities. Their proposed age limit also was, in part, refuted by Seethaler and Fuchs (2006), who reasoned that if that were the case, there would be no differential performance of computational estimation among their third-grade participants. Results from that study show that students in the low-ability group scored significantly lower than the average-ability group, who scored significantly lower than the high-ability group.

Lastly, a similar set of baseline data for computational estimation by American students may be needed such that more could be derived to inform American educators. Further studies in this respect are suggested.

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Beginning Mathematics Teachers' Beliefs of Subject Matter and Instructional Actions Documented Over Time

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In this study we report the results of survey research that collected responses of an identical sample (31 beginning mathematics and science teachers, elementary and middle school level) that graduated from a reform-based mathematics and science teacher preparation program, the Maryland Collaborative for Teacher Preparation (MCTP). Our aim was to compare responses of the same beginning teachers over the two administrations of the survey. We administered the identical survey instrument in two separate batches spreading over nearly a four-year period (1st batch fall 1999 through fall 2001; 2nd batch summer 2002). The first administration (pre-test) was conducted soon after the beginning teachers graduated from the teacher preparation program and had not started full teaching. The second administration (post-test) was conducted after the new teachers had taught full time for a minimum of a full year, with the majority having taught for two years. The instrument was crafted to measure the constructs of interest, MCTP Teacher's Beliefs and Actions of Mathematics and Science. Results for teachers who taught for at least two years indicated that in all areas the MCTP teachers maintained their reform-based beliefs and actions after their induction years. These findings provide evidence for the sustainability of positive impact in the workplace resulting from a reform-based undergraduate teacher preparation program.

Researchers in mathematics teacher education continually question and study the impact of teacher preparation on the future teachers who graduate from their programs (e.g., Ensor, 2001; Steele, 2001). Although many studies have been designed to create changes in the conceptions of prospective and practicing teachers (e.g., Cooney, Shealy, & Arvold, 1998; Raymond & Santos, 1995; Steele & Widman, 1997) very few studies have examined whether and how these changes in conceptions have been sustained through the beginning years of teaching. Motivated by a critical shortage of mathematics teachers and the need to have long-term access to changing and building future teachers' beliefs in support of reform efforts, the Maryland Collaborative Teacher Preparation (MCTP) program, was designed to generate new understandings in reform-based undergraduate mathematics and science teacher preparation. In this study, our aim was to compare responses of the MCTP teachers soon after they graduated from the reform teacher preparation program (pre-test) and after they had taught full time for a minimum of a full year, with the majority having taught for two years (post-test).

When teacher interns enter their initial practicum experience they are confronted with differing teaching philosophies, their own, their university professors, and their school mentors (Sullivan, Mousley, & Gervasoni, 2000). In this situation, teacher interns struggle to find their own niche in teaching and have to learn to reflect being both a learner and a teacher (Kelly, 2000). Too often, many of the pedagogical strategies emphasized in their college methods classrooms are lost when they enter their field-based sites. This is due to the barriers they face, such as differing teaching styles between mentors and interns, time factors, particular classroom situations, and lack of support from mentors and supervisors (John, 2001). Ziechner and Tabachnick (1981) described the attitude shift that student teachers make when they moved from university course work to school teaching. They highlighted the regression in students' attitudes toward more traditional viewpoints as they become immersed in the profession. There were only few studies (e.g., Huffman, Thomas, & Lawrenz, 2008; Loughran, 1993; Steele, 2001; Wingfield, Freeman, & Ramsey, 2000) that explored whether perceived changes in conceptions of teacher interns were sustained over time, that is, through the first years of teaching. Such longitudinal studies could help teacher educators and researchers deepen their understanding of how or whether teachers reconceptualize their teaching practice to include their new conceptions.

Huffman et al. (2008) examined the science and

mathematics instruction of teachers who were initially prepared by the Collaboratives for Excellence in Teacher Preparation program (CETP) and compared them to a sample of teachers who were not prepared by CETP. The focus of their study was on examining the extent to which science and mathematics teachers (6th-12th grade teachers with 1-5 years of experience) used more reform-oriented instructional practices in their classes when they entered the teaching profession. This study included non-CETP and CETP science and mathematics teachers as well as their students. The authors found,

> An examination of the raw teacher and student survey results indicates that both science and mathematics teachers actually had relatively low levels of use of reform strategies. The majority of instructional strategies on the survey were only used in the 'seldom' to 'occasionally' range. In other words, both science and mathematics teachers used reform techniques less than envisioned in the standards (p. 144).

Steele (2001) contrasted four elementary teachers who were graduates of a teacher education program that incorporated a reform-based mathematics methods course. Her report provided results from a longitudinal study that extended from the time that the participants were teacher interns until the end of their second year of full-time teaching. The case studies indicate that two of the four teachers sustained their cognitively based conceptions about mathematics teaching and learning, and implemented these conceptions into practice. The other two did not. The analysis suggests that there were several factors that influenced the teachers' conceptions and the choices they made in their teaching: personal commitment, professional strength, curriculum planning, assessment, beliefs, knowledge, and support from the school administration.

In our study we focused primarily on the MCTP teachers' beliefs and attitudes towards mathematics and mathematics teaching. A variety of terms are used to define teacher beliefs. These include preconceptions, implicit theories, and orientations. While definitions differ, it is generally agreed that teachers' beliefs about what mathematics is and what it means to learn mathematics directly impact how they teach mathematics (Ernest, 1989; Szydlik, Szydlik, & Benson, 2003). For example, Thompson (1984) found that a teacher who viewed mathematics as a collection of facts and rules to be memorized and applied was more likely to teach in a prescriptive manner, emphasizing rules and procedures conveyed by the teacher. On the other hand, a teacher who held a problem-solving view of mathematics was more likely to employ activities that allow students to construct mathematical ideas for themselves.

When practicing teachers were young learners they often learned in teacher-centered classrooms by listening to lectures, memorizing information, and practicing rote computations. Ernest (1989) suggested that teachers who learned mathematics in these ways most likely to conceive of mathematics in the instrumentalist view, a conception that mathematics is a collection of unrelated facts, rules, and skills. Swars, Hart, Smith, Smith, and Tolar (2007) recently argued that "in mathematics education it is not uncommon for beginning pre-service teachers to come to their teacher preparation programs with a traditional view of what it means to know and do mathematics: a view of mathematics as a fixed body of knowledge to be delivered to children, usually through clear, organized presentations and lectures" (p. 325). In contrast, mathematics teachers, teacher educators, and researchers involved in the current reform movement in mathematics education recommend that students need to be actively involved in constructing their own knowledge and developing mathematical concepts that require them to explore, explain, and justify solution strategies to mathematical tasks (National Council of Teachers of Mathematics [NCTM], 2000). Teaching mathematics in this way coincides with the problem-solving view of mathematics, a conception that mathematics is expanding continually through human inquiry. For many teachers, this reform-based approach to teaching mathematics requires a change in beliefs about mathematics and about what it means to learn and teach mathematics (Ernest, 1989).

A teacher's past events create "guiding images" that act as a filter for new information. A belief structure created from an earlier experience may also be resilient enough to become the standard to which newer information is compared. For example, if a teacher changes conceptions of what quality teaching is, from a traditional whole group approach to a cooperative learning orientation, all new information about practice will be filtered through the cooperative learning belief structure (Blake, 2002).

Leinhardt (1990), as well as Bryan and Atwater (2002), demonstrated in their research on teacher thinking that teachers' beliefs about the teaching-learning process played a significant role in determining the nature of teachers' purposes in the classroom and directly

affected many aspects of their professional work, including lesson planning, assessment, evaluation and teachers' decision-making during classroom interactions with students.

Studies from different perspectives were designed to document and interpret the effectiveness of the MCTP program. McGinnis (2002, 2003) measured MCTP and non-MCTP teacher interns' attitudes and beliefs about mathematics and science teaching and found the MCTP teacher interns' attitudes and beliefs to be more aligned with the overall program goals than the non-MCTP controls. Moreover, he found that over 2.5 years the MCTP teacher interns' attitudes and beliefs continued to move in the desired direction. Roth-McDuffie, McGinnis, and Graeber (2000) in a case study of MCTP mathematics content course found that the interns benefited from the transformative vision of mathematics portrayed by the instructor. In previous studies (Marbach-Ad & McGinnis 2008; McGinnis & Marbach-Ad, 2007), we measured the new MCTP teachers' beliefs, attitudes and practices and compared them with a national sample of teachers. The MCTP teachers' responses were more in alignment with desired responses. McGinnis, Parker, and Graeber (2004) also conducted case studies of the MCTP interns and MCTP new teachers and reported how they perceived their MCTP instructors as modeling reform-based teaching and how they later implemented that vision of teaching in their own teaching practices in precollegiate level classrooms.

In this study we used the same reliable and validated "MCTP Teacher's Actions and Beliefs of Mathematics and Science" survey to compare between teachers' attitudes and beliefs towards mathematics and mathematics teaching with which they entered workplace and after two or three years of full time teaching. We wanted to answer the question: To what extent do MCTP teachers maintain their beliefs and intended instructional actions in mathematics as they are inducted in schools? To test this question, we focused our study on these highly significant research questions:

1. Do MCTP teachers maintain their beliefs about the nature and teaching of mathematics over extended practice (induction years and beyond)?

2. Do MCTP teachers maintain their perceptions about students' skills required for success in mathematics over extended practice?

3. Do MCTP teachers maintain their familiarity with standard documents for mathematics over extended practice?

4. Do MCTP teachers maintain their intentions about implementing reform activities in mathematics classes aligned more with the reform-based recommendations over extended practice?

Research Design and Methodology

The Context of the Study - The MCTP Program

The MCTP was a statewide, standards-based program for undergraduate students who planned to become specialist mathematics and science upper elementary or middle level teachers. The goal of the MCTP was to promote the development of teachers who were confident teaching mathematics and science, who could make connections between and among the disciplines, and who could provide an exciting and challenging learning environment for students of diverse backgrounds (University of Maryland System, 1993). This goal was in accord with educational practice reforms advocated by the major professional mathematics and science education communities in the past decade and present day (American Association for the Advancement of Science [AAAS], 1993; National Academy of Sciences [NAS], 2006; National Council of Teachers of Mathematics [NCTM], 1989, 1991, 2000; National Research Council [NRC], 1996;). As such, the innovations of the MCTP included: (a) introduce future teachers to standards-based models of mathematics and science instruction; and, (b) provide courses and field experiences that integrate mathematics and science (see Appendix A for MCTP goals overview).

In practice, the MCTP undergraduate courses were taught by faculty in mathematics, science, and education who made efforts to focus on "developing understanding of a few central concepts and to make connections between the sciences and between mathematics and science" (MCTP, 1996, p. 2). Faculty also sought to infuse technology into their teaching practices, and to use instructional and assessment strategies recommended by the literature to be compatible with the constructivist perspective (i.e., address conceptual change, promote reflection on changes in thinking, and stress logic and fundamental principles as opposed to memorization of unrelated facts) (Cobb, 1988; Driver, 1987; Tobin, Tippins, & Gallard, 1994; von Glasersfeld, 1989).

Salient features of all the MCTP reform-based courses were that faculty lecture was diminished and student-based problem solving was emphasized in cross-disciplinary mathematical and scientific applica-

tions. Cooperative learning strategies were used extensively. Statewide, the MCTP offered nearly 90 reformed-based courses in mathematics, science, and methods.

Teacher interns selected to participate in the MCTP program were in many ways representative of typical teacher candidates in elementary teacher preparation programs. Where they differed prominently was in their willingness to specialize in the teaching of mathematics and/or science by making connections between the two disciplines. Once in the MCTP program, the MCTP teacher candidates were distinguished from all other candidates by taking 36 credits of mathematics and science courses (18 hours of each discipline). This was contrasted starkly with elementary teacher candidates who chose not to emphasize either mathematics or science as field of concentration who were required to earn a total of 11 credits in mathematics and 8 in science as well as 18 in their chosen field. Non-MCTP elementary teacher candidates who chose to emphasize mathematics (only) had to earn 18 credits in mathematics and 8 in science. Candidates with a science (only) emphasis had to earn 18 credits in science and 11 in mathematics. The MCTP content courses (open to all teacher interns) were transformed to conform to the MCTP program goal. Mathematics courses were distributed across four areas: algebra/number, probability and statistics, geometry, and calculus.

The "MCTP Teacher's Beliefs and Actions of Mathematics and Science" Survey. In this study we used a reliable and valid tool that was crafted for our previous studies and was used to compare between our group of graduate students and a national sample of teachers (McGinnis, 2002). The tool that we used, *"MCTP Teacher's Beliefs and Actions of Mathematics and Science"* aimed to measure the constructs of interest of the program's graduates. Appendix B contains a complete copy of the MCTP survey. The constructs we measured were "Teachers' beliefs about mathematics (9 items)," "Teachers' beliefs about science (9 items)," "Teachers' use or intended use of instructional practices in mathematics (7 items)," "Teachers use or intended use of instructional practices in science (7 items)," "Teachers' perceptions about student success in mathematics (6 items)," "Teachers' perceptions about student success in science (6 items)," "Teachers intentions about implementing reform activities in mathematics classes (6 items)," "Teachers' intentions about implementing reform activities in science classes (6 items)," "Teachers' knowledge of the mathematics and science standards" (3 items), and 4 items that asked background information. In this study we report on students' beliefs and attitudes towards mathematics and mathematics teaching only and not towards science and science teaching (Marbach-Ad & McGinnis, 2008).

To establish face validity of our instrument (i.e., that there existed a connection between the surface features of the instrument's content and the theoretical construct (Smith & Glass, 1987), we provided for inspection the draft instrument to a sample of mathematics content experts and a sample of mathematics pedagogy experts (we reported on its reliability in McGinnis & Parker, 2001). Our theoretical constructs consisted of beliefs about the nature and teaching of mathematics. Namely, we sought to determine if the MCTP graduates held beliefs about mathematics content that aligned with a traditional view of mathematics as a static and codified body of knowledge or a view of the discipline as a dynamic way of knowing driven by inquiry. Regarding the teaching of mathematics, our aim was to measure if our graduates held beliefs about the teaching of mathematics that were teacher-centered or learner-centered, as characterized by passive learning (lecture) or active learning (problem solving), respectively. The surface content of the instrument consisted of the items selected from a limited number of existing instruments as well as three new items that measured beliefs about subject matter integration and knowledge about the major standards documents. The content specialists included a mathematics professor, two mathematics methods professors, and three mathematics education doctoral students. The result of the inspection by our sample strongly supported the face validity of our instrument.

Sample and Data Analysis

For our study we used a pre-post analysis. We administered the identical survey instrument by mail to the MCTP program's graduates in two separate batches spreading over nearly a four-year period (1st batch fall 1999 through fall 2001, $n = 113$; 2nd batch summer 2002, $n = 68$). The pre-test was conducted soon after the beginning teachers graduated from the teacher preparation program and had not started full teaching. The response rate for the pre-test was 60% ($n = 68$). The post-test (only to those who responded to the first one) was conducted after the new teachers had taught full time for at least one full year, with the majority having taught for two years. The response rate for the post-test was 60% ($n = 42$), a relatively good response rate for survey research that targets new teachers. Re-

sponses came from graduates of all seven of the MCTP participating institutions with baccalaureate programs. We attribute the high level of response partially to the strategies for increasing return rates to mail-in surveys suggested by Dillman (1978) (i.e., sending a token honorarium such as a $2 bill or a $1 coin in the first mailing and a $20 honorarium in our final mailing, sending a later reminder letter with another copy of the instrument, and using email and telephone reminders). To enhance the validity of our analysis, we conducted a nonresponse bias check in both administrations by randomly selecting a sample of 8 non-responding MCTP graduates. Upon contact, we encouraged them to complete the survey. We then compared their responses to those responses we had earlier collected. No differences were detected. Therefore, we believe our sample represented the entire population of MCTP teachers who had responded earlier to the survey when they graduated from the program.

For comparison purposes we only report results from the surveys of the sampled MCTP graduates that at the time of the second survey had completed 2+ years of practice (31 graduates): Approximately 50% were middle school teachers and 47% were elementary teachers. We analyzed the survey responses in different ways – using t-test and chi square analyses, and using analysis for the whole survey and for separate group of questions. We decided that due to the small sample and the large variability between the different items in the survey that we should simply compare percentages for each of the items and use chi square tests to compare between responses to each item on the pre- and post-test. Another reason for using the chi square analysis was that since we were using a survey for which we had reliability and validity documentation, we couldn't change the items or the structure of the survey without recalibrating the survey's reliability and validity. However, please note that in this application of the survey in one subsection we used a different Likert point scale. For the chi square analysis we condensed the scale always to two categories (see results section). The crosstab analysis for each item also enabled us to examine the differences between specific students and learn if they changed their perspectives towards each item between the pre- and post-test.

Data sources also included individual participant semi-structured interviews of all the MCTP beginning teachers (each 1 hour in duration, four times per year, recorded and transcribed); focus group participant interviews (each 2 hours in duration, twice per year, recorded and transcribed). For this study, we read carefully through the extensive interview transcriptions of the MCTP new beginning teachers (n =6) who graduated in the first cohort from one of the participating institutions.

Teacher 1: Female, teaching mathematics and science in fourth grade.

Teacher 2: Female, teaching mathematics and science in third grade.

Teacher 3: Female, teaching mathematics and science in seventh grade.

Teacher 4: Male, teaching mathematics and science in eighth grade.

Teacher 5: Female, teaching mathematics and science in seventh and eighths grades.

Teacher 6: Female, teaching mathematics and science in eighth grade.

We report illustrative comments by MCTP new teachers to enhance the MCTP teachers' written survey responses. While we make no claims that they are necessarily representative of all MCTP new teachers' viewpoints, we offer them as a way to interpret more fully the survey responses. The comments were culled from interview questions that were recorded and transcribed for analysis. Examples of the interview questions include: "To what extent, and in specific ways, do you think what you learned in your MCTP teacher preparation program has impacted how you are teaching mathematics and science?" "Do you see yourself making connections between mathematics and science?" "How about technology?" "How about alternative assessment for the MCTP program? In comparing your teaching of mathematics and science with other teachers at your school, both veteran and new, in what ways do you think your teaching is the same or different? How about school personnel?

In this paper, we used the selective MCTP new teachers' interview responses to support and illuminate how teachers interpreted related questions, and not to draw any collective conclusions. Therefore, we did not find that it is necessary to elaborate here on the background of these teachers and their schools. These interviews are fully documented in a previous study that takes an in-depth case study approach for research (McGinnis et al., 2004),

It is recognized that research based on statewide mathematics teacher preparation reform efforts are very rare (see Wingfield et al., 2000). Athough our sample size is on the small side for quantitative research (N = 31) we believe that this study adds signif-

icant information to the emerging literature on beginning mathematics teachers (a sample known as difficult to recruit in educational studies).

Results

We report our findings according to the four categories in the MCTP survey. First we examined to what extent the MCTP teacher responses to the pre-test (in their first year in school) aligned with the philosophy of the MCTP program. Next, we compared the responses of the first survey to the responses of the post-test (after two or three years in school) as a way to determine if the teachers maintained their beliefs after two or three years in their workplace.

1. Teachers' beliefs about the nature and teaching of mathematics

In this section teachers were asked to rate on a scale from 1 to 4 (1= strongly disagree, 4=strongly agree) nine statements concerning their beliefs about the nature and teaching of mathematics (see Appendix B, 1-9). Table 1 shows the MCTP teachers responses to the first and the second surveys; the percentages in this table reflect the combined proportion of teachers who either agree or strongly agree with the statements. We report the number of respondents before each percentage, since the sample size was relatively moderate (N=31).

Table 1 shows that there were significant differences between students' responses in the first and the second survey regarding to the first item *Math is primarily an abstract subject.* Inspection of the data shoes that only two MCTP teachers came to their workplace (first survey) with the belief that "Math is primarily an abstract subject." However, in the second survey four more teachers agreed with this statement. We believe this finding makes sense, since in the two years of teaching the teachers could have experienced for the first time through their students eyes (and not through their own eyes) how elementary and middle school students perceive mathematics.

Most of the MCTP graduates (more than 77%, see Table 1) came to school with the beliefs that "Math is primarily a formal way of representing the real world" and "Math is primarily a practical and structured guide for addressing real situations." Based on earlier documentation of the MCTP mathematics and science content courses, we know that the MCTP graduates were prepared to teach mathematics problems using real sit-

Table 1

Comparison Between the Responses of the First and Second Survey of MCTP Teachers' Beliefs About the Nature and Teaching of Mathematics by Number (and Percentage) Responding "Agree" or "Strongly Agree"

Item	First Survey	Second Survey
1. Math is primarily an abstract subject.	2 (6.5%)	6 (19.4%)**
2. Math is primarily a formal way of representing the real world.	42 (77.4%)	24 (77.4%)
3. Math is primarily a practical and structured guide for addressing real situations.	29 (93.5%)	29 (93.5%)
4. Math should be learned as sets of algorithms or rules that cover all possibilities.	7 (23.3%)	4 (13.3%)
5. A liking for and understanding of students are essential for teaching math.	28 (90.3%)	29 (93.5%)
6. If students are having difficulty, an effective approach is to give them more practice by themselves during class.	4 (12.9%)	4 (12.9%)
7. More than one representation should be used in teaching a math concept.	29 (93.5%)	31 (100%)
8. Some students have a natural talent for math and others do not.	23 (74.2%)	25 (80.6%)
9. Basic computational skills on the part of the teacher are sufficient for teaching elementary school math.	9 (2.9%)	8 (25.8%)*

Note. * $p< 0.05$. ** $p< 0.01$.

uations. As result, their support of statements such as "*Math is primarily a formal way or structured guide to address real situations"* was expected, at least initially, when they began teaching full time. However, we wondered if the MCTP graduates would maintain these beliefs after an extended time in the workplace. We found that there were no differences between the percentages of teachers who agreed with these statements in the first and second survey. Therefore, after two years of teaching, the MCTP graduates maintained their beliefs that real world situations should be used in mathematics teaching. In an interview one MCTP teacher said:

> ...They [the students] did a thing where they had to do a graph. I had this data on different roller coasters – how long they are, how fast they go, how much time is on it. So they did a graph. You know, if it's this long it goes this fast... (Teacher 2).

Regarding the teaching of mathematics, most of the MCTP teachers (more than 90%) agreed in the first, and even more in the second survey (Table 1), with the following statements: "A liking for and understanding of students are essential for teaching math" and "More than one representation should be used in teaching a math concept". These statements are aligned with the MCTP philosophy, which stresses that teachers should understand the variability in students' nature and learning styles and thus use multiple representations that are understandable for different types of students. As one MCTP teacher said in the interview:

> We have a real push in the school for differentiating math, because we don't switch for math, and so I have real, real low kids and real, real high kids – ability level, so we are pretty much forced to have two or three kinds of activities going on at once within an hour period.... I know that it is a real frustration for a lot of teachers... but I don't have a problem with having two or three things going on at once... (Teacher 3).

We also believe that the variation in students' ability level that this teacher characterized is likely one of the reasons that more than 70% of the teachers in both surveys agreed with the statement "Some students have a natural talent for math and others do not."

Most of the MCTP graduates **did not agree** (about 70%) in the pre-test, and even more in the second survey, with the following statements: "Math should be learned as sets of algorithms or rules that cover all possibilities" (87%), "If students are having difficulty, an effective approach is to give them more practice by themselves during the class" (87%), and "Basic computational skills on the part of the teacher are sufficient for teaching elementary school math" (75%). These findings are aligned with the MCTP philosophy, since the MCTP program was designed around the recommendations to teach math through inquiry-based learning and not through a memorization of a set of algorithms and rules, and to involve students with discussion and group study instead of more self-practice. In addition, in the schools the MCTP teachers took positions there was a major recommendation to use telecommunication and teaching based technology, even in the elementary schools.

It is noteworthy that teachers complained that when teaching math (more so than for those concerning science) it was really difficult for them to use inquiry-based teaching and innovative approaches. They voiced that their major constraint was the overloaded curriculum and material coverage expectations that their district's central offices enforced. One teacher said:

> I feel like I'm sort of handcuffed in a way [because of the county's assessment, monitoring, and reporting system] in the county, I'm limited and probably shouldn't cover subjects to the depth that I do, because I should moving on to the next objective" (Teacher 4).

Another teacher said:

> My main problem was that the objectives of the county really kind of hurry you through it....you're supposed to cover eight objectives per quarter...in the beginning I was really kind of worried about getting into trouble...but now I'm kind of thinking more about what's better for the kids and okay if we just don't get to that one at the end of the year (Teacher 3).

2. Teachers' perceptions about students' skills required for success in mathematics

In this section teachers were asked to rate on a scale from 1 to 3 (1 = not important, 3 = very important) the importance of particular kinds of skills for success in the discipline. These skills have elements ranging from remembering through understanding to thinking creatively (Appendix B, 19-24). Figure 1 shows the MCTP graduates responses to the first and second surveys concerning students' skills required for success in

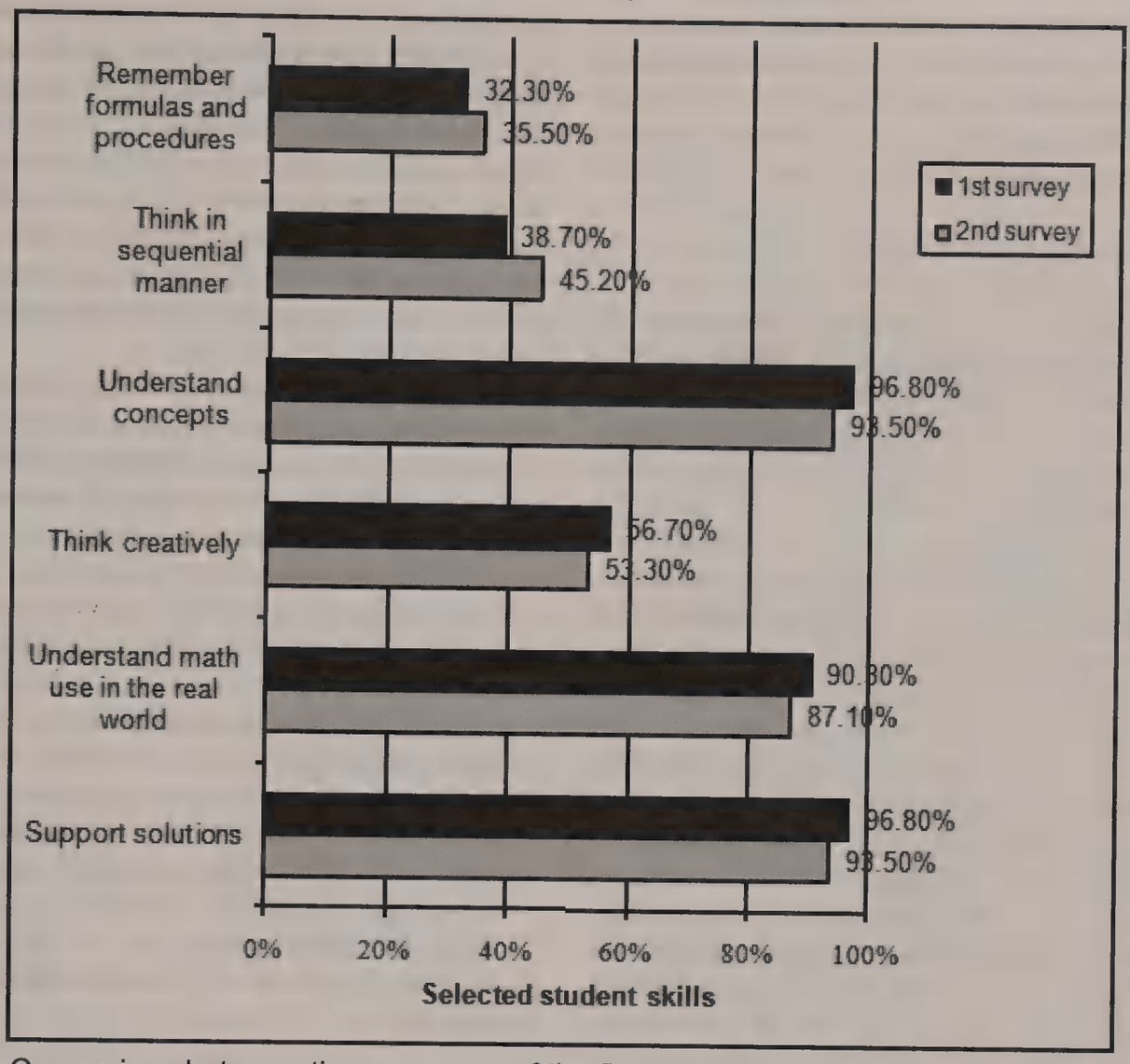

Figure 1. Comparison between the responses of the first and second survey of MCTP teachers' perceptions of student skills required for success in mathematics by percentage responding "very important".

mathematics. The percentages in this figure reflect the percentage of teachers who choose the category "Very important."

Figure 1 shows that the MCTP graduates were consistent in their responses to the first and second surveys concerning the aptitudes and skills students need to succeed in learning mathematics. In both administrations around 90% of the teachers consider it very important for students to understand concepts, to understand how the subjects are used in the real world, and to be able to support their results and conclusions. Around 60% of the teachers considered it very important to think creatively and less than 45% of the teachers considered it very important to think in a sequential manner and remember formulas and procedures.

The fact that only around 30% of the MCTP graduates marked "remember formulas and procedures" as very important is consistent with the overall goals of the MCTP. The major reform-based recommendations are to put the emphasis on meaningful learning (characterized by a focus on understanding) instead of rote learning (characterized by memorization of facts). The MCTP philosophy, while not rejecting the importance of "remembering," emphasizes that learning in school should expand to include a fuller range of cognitive processes, such as the ability to use what was learned to solve new problems, answer new questions, or facilitate learning new subject matter.

One MCTP teacher in an interview complained about the fact that her workplace made it difficult to teach for understanding:

> I'm not always able to use everything that I taught in MCTP, because time constraints, and because of curriculum requirements of the county, and because of the level of reasoning of some of the students.... For students applying knowledge – that's

one of the toughest things is when we will give them quiz or something that asks them to apply something that they have learned to a new situation… they are better at just remembering or memorizing sorts of questions.

However, she specifically referred to the way the MCTP program impacted her teaching:

…A lot of the stuff that we learned about in MCTP was higher order thinking and questioning…. I do try and use hands-on sorts of things and that's something I know I learned at MCTP…and projects in math, math projects sorts of things instead of giving big tests (Teacher 5).

3. Teachers' familiarity with standards documents

In this section teachers were asked to rate their familiarity with standards documents on a scale from 1 to 5 (1 = not at all familiar, 5 = familiar to great extent). In both surveys, only around half of the teachers marked that they are "fairly familiar" or "very familiar" with the NCTM (1989) standards.

4. Teachers' intentions about implementing reform activities in mathematics classes

In this section of the survey teachers were asked to report on the kind of reform activities they intended to or were able to implement in their classrooms (items 34-40). Table 2 summarizes the MCTP graduates responses. The percentages reflect the percentage of teachers who choose to answer "yes."

Overall, a large majority or all of the MCTP teachers reported that they used each of the instructional practices that were included in this section in their mathematics instruction. The exception being "using telecommunication supported instruction" which was lower (approximately 60%). These results are encouraging since it indicates that the MCTP teachers maintained over time there beliefs about the importance of using key reform-based practices, including "using authentic assessments (100%)," "using standards aligned curricula (100%)," and "making connections with science" (97%). In the following we elaborate on some practical aspects that teachers mentioned in their interviews.

A. Assisting all students to achieve high standards and providing examples of high-standard work

Almost all of the teachers in the first and the second survey (above 90%) answered that they assisted all students to achieve high standards and provided examples of high-standard work. MCTP teachers in interviews said that the background knowledge they acquired in the MCTP program enabled them to help students to better achieve:

…I do have a lot more background knowledge. I even noticed that I have more so than the veteran teachers that are here [her teammates]…. It was part of the MCTP requirements… I'm teaching my kids [fourth graders] things that they learn in middle school. And the kids are getting it because I'm doing it hands-on type way and I'm not just throwing it at them…I'm doing a lot extension stuff… (Teacher 1).

B. Use authentic assessments

Almost all of the teachers in the pre-test (93.5%) and the post-test (100%) answered that they used authentic assessments, even though they also had to use their public school district's formal assessments:

Table 2
Comparison Between the Responses of the First and Second Survey of MCTP Teachers' Use of Instructional Practices in Mathematics by Percentage Responding "Yes"

Item	Mathematics	
	First	Second
34. Assisting all students to achieve high standards.	90%	100%
35. Providing examples of high-standard work.	93.5%	100%
36. Using authentic assessments.	93.5%	100%
37. Using standards aligned curricula.	93.5%	100%
38. Using standards-aligned textbooks and materials.	87.1%	100%
39. Using telecommunication-supported instruction.	56.7%	60%
40. Making connections with science.	90.3%	96.8%

> At the beginning of the year I was giving a lot math quizzes, every Friday, and tests … Now, I've been giving the ISM's [ISM's were Instructional System in Mathematics countywide content exams for the students linked to the county's curricula], because we have to, but I've also been doing a lot of learning station things and walking around and assessing how they react to different problems… and I keep math journal, a science journal…. We've done a lot hands-on things and discussions, and just seeing their responses in their journals, and that's how I've grading them – group participation in lab and things like that… I definitely stepped away from the formal assessment (Teacher 1).

The MCTP program recommends strongly using authentic assessments. The call for "Science and Mathematics for all" (Fey, 2002, p. 119) meant that teachers would be required to assist all students to achieve high standards, and to reach all the students. There was a need to use different assessment strategies, since for many students the conventional testing paradigms do not give accurate readings of their knowledge (Fey).

C. Use standards-aligned curriculum, textbooks and materials

Most of the teachers in the pre-test (87.1%) and the post-test (100%) answered that they use standards-aligned curriculum, textbooks and materials in teaching mathematics. However, in the interviews, the MCTP teachers raised the dilemma about how to use textbooks. One MCTP teacher complained about her more veteran teammates who pushed her to use the textbook in a traditional way:

> …They [other two third grade teachers] keep on pushing these textbooks in my face and they keep on saying, "you have to use this. They [the students] have to answer questions from it."' We do answer questions, I mean, we do write in a daily log and we do, um, discuss, but we don't read the whole section in book – a chapter and than answer corresponding questions to it.…They [the teacher's teammates] think they cover more things…. I say, "Well you may cover more things and the students may remember it short-term…" (Forum group: Teacher 1).

D. *Making connections between science and mathematics*

Almost all of the teachers in the first and the second survey teachers (above 90%) answered that they were making connections between mathematics and science in their practices. One of the fourth grade MCTP teachers, in an interview, was asked, "How about making connections between math and science? Do you see yourself as the same or different as the teachers in your school?" She responded in this way:

> Well it's kind of hard for my other teammate to make connections because she doesn't teach the science... definitely because I'm so math and science, really concentrated on both subjects and teaching both of them, It's definitely not to the same level as I am. (Teacher 1).

Another teacher of 7th and 8th grades stressed the point that because she was teaching both mathematics and science she was better able to make connections between them in comparison to other teachers: "When I'm in math I know what they're studying in science, and so sometimes, I might pull something in from them" (Teacher 5).

Another teacher stated:

> The county curriculum has it [mathematics and science] separated, but within, like it is easier for me to draw math into science… Right now we're starting a unit on plants and so they'll be growing and we'll be graphing and, you know, taking down data and making generalizations… (Teacher 6).

Teachers also talked about how students react to their effort to connect mathematics and science,

> …The other day in math we were talking about distance and scientific notation and I was talking about distance to planets and looking at the angles of planets, and how people used to measure how far away stars were and all that stuff. And they'd say [the students], "How is it that you know this? You're a math teacher. And, oh, that's right. You're a science teacher too." So I can bring things from one area to the other and use them in class (Teacher 5).

E. Using telecommunication-supported instruction

Only about 60% of the MCTP teachers reported in both surveys using telecommunication-supported instruction in mathematics instruction. These percentages are low in comparison to the other practices that MCTP teachers indicated that they used. In the interviews the MCTP teachers were asked to refer to their use of technology in general in their classrooms and the teachers' responses appropriately explain the low usage of tech-

nology and telecommunication:

> I'm not as pleased with that [the use of technology] as everything else I've been doing. I have a lot of complaints just about the way our technology is distributed... I tried to use digital camera for something and nobody can find the chargeable batteries... and they send you back... and apparently there are all these color printers in our buildings, apparently there are 13 but nobody knows where a single one is". (TEACHER?)

Although there were a lot of frustrations about using technology in schools, some teachers also reported good experiences:

Teachers' reports about their classroom experience in their second year of teaching

Based on the pre- and post-test of the MCTP surveys, we conclude that the MCTP reform-based philosophy was not "washed out" after two or three years of teaching. In fact, in some cases, the MCTP teachers felt more comfortable using the MCTP philosophy in the second year of teaching, as they were more experienced. One teacher said:

> The first year, I was trying to do all these cool lessons. Now I realize the lessons I did last year are not as strong as the ones I'm doing this year because I have so much more experience with it. Like I was doing little bits and pieces of everything. And the kids were like, "Wow, wow, wow!" But now I'm kind of able to like put together an entire thing. Like all-encompassing. And it's just complete. ... It's been really good because I'm seeing the lessons are so much more, they were structured, but now they're more creative (Teacher 2).

Another teacher said:

> What I do notice is that more and more experience I get, how much easier it is for me. And I think because I have that solid foundation already, it's really helped me teaching.... Now it just comes much easier to me because I have been taught in the constructivist way. You know, this whole idea of teaching. And it's just something I can't forget, I don't forget anything that I've learned in the courses that I took because it's been very helpful to me (Teacher 1).

Discussion and Implications

The goal of the MCTP was to graduate teachers who were confident teaching mathematics (and science) using technology, who could make connections between and among the disciplines, and who could provide an exciting and challenging learning environment for students of diverse backgrounds. Consistent with other research (i.e., Lawrenz, Huffman, & Graves, 2007; Swars et al., 2007), earlier MCTP studies presented evidence (using both quantitative and qualitative methodologies) that the new MCTP teachers had experienced transformative mathematic content and methods courses and began teaching with the skills, dispositions, and knowledge targeted by the MCTP program (McGinnis, 2002, 2003; McGinnis & Parker, 2001; Roth-McDuffie et al., 2000).

The current study, based on repeat survey methodology and informed by teachers' interviews, shows that the MCTP teachers report that they maintain over time their initial, reform-based orientation and mathematics practices with which they began their teaching careers. Along all measures, the present analysis indicates that the graduates of the MCTP program conveyed the targeted reform-based beliefs and perspectives to the workplace, and, most importantly, that they maintained them during their induction years and beyond. It is encouraging that the full time teaching experience in the schools did not undermine the teacher change in beliefs as was earlier reported by Ziechner and Tabachnick (1981). The stability of these beliefs during their two years of teaching suggests that the distinctive features of the teacher preparation program helped in developing well-established beliefs.

The MCTP teachers reported beliefs defined in the literature as a good indicator for their actions and teaching performances (Pajares, 1992; Richardson, 1996; Wilkins & Brand, 2004). However, we are aware that studying beliefs is somewhat problematic because they cannot be directly observed and must be ascertained by what people say and do. Sometimes, teachers do not possess the language with which to express their beliefs; other times, they may be reluctant to express unpopular beliefs (Leinhardt, 1990). Nevertheless, by analyzing our surveys we can conclude that the MCTP teachers are knowledgeable about the types of viewpoints they are expected to hold as transformative, reform oriented teachers. And through our analysis of MCTP teacher interviews we have additional support that the MCTP teachers carried out the philosophy of the MCTP program into their beginning years of teaching.

A clear implication for policy includes the critical need to continue to support innovative, transformative

mathematics teacher preparation programs. In particular, the major implementation features in the MCTP that warrant support as a set of innovations in mathematics teacher preparation included: reformed based content and pedagogy courses taught by faculty who have engaged in sustained professional development; summer internships in mathematics rich environments; and well-prepared student teacher mentors in the schools.

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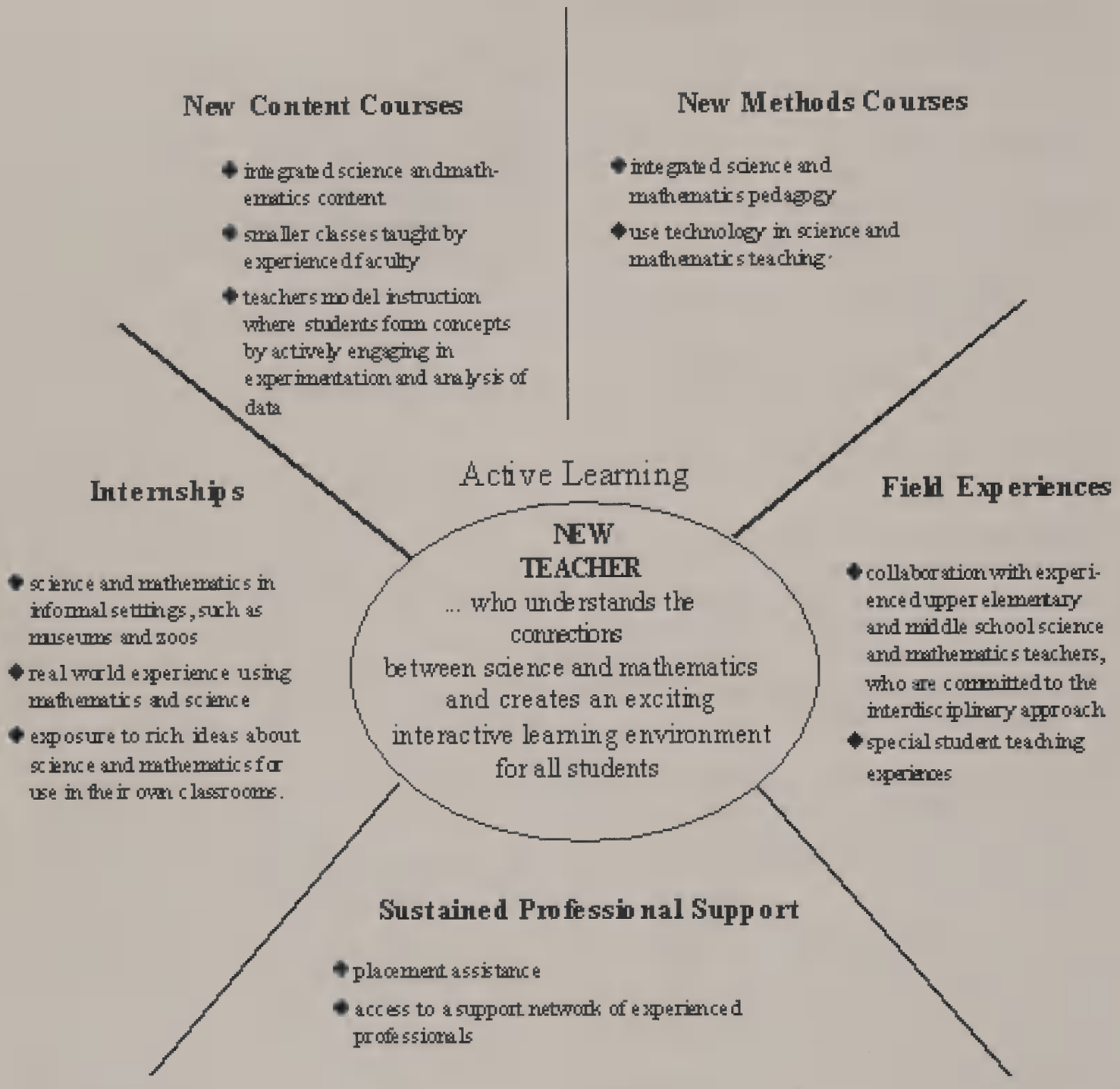
Appendix A

The MCTP Philosophy


New Content Courses
integrated science and mathematics content
smaller classes taught by experienced faculty
teachers model instruction where students form concepts by actively engaging in experimentation and analysis of data
New Methods Courses
integrated science and mathematics pedagogy
use technology in science and mathematics teaching
Active Learning
NEW TEACHER
... who understands the connections between science and mathematics and creates an exciting interactive learning environment for all students
Internships
science and mathematics in informal settings, such as museums and zoos
real world experience using mathematics and science
exposure to rich ideas about science and mathematics for use in their own classrooms.
Field Experiences
collaboration with experienced upper elementary and middle school science and mathematics teachers, who are committed to the interdisciplinary approach
special student teaching experiences
Sustained Professional Support
placement assistance
access to a support network of experienced professionals

Appendix B

MCTP Teacher's Actions and Beliefs of Mathematics and Science

Directions: Please select the letter response that best represents your actions and beliefs.

SECTION I.

To what extent do you agree or disagree with each of the following statements?

Choices:

(A)	(B)	(C)	(D)
Strongly disagree	**Disagree**	**Agree**	**Strongly agree**

Mathematics

1. is primarily an abstract subject.
2. is primarily a formal way of representing the real world.
3. is primarily a practical and structured guide for addressing real situations.
4. should be learned as sets of algorithms or rules that cover all possibilities.
5. A liking for and understanding of students are essential for teaching math.
6. If students are having difficulty, an effective approach is to give them more practice by themselves during the class.
7. More than one representation should be used in teaching a math concept.
8. Some students have a natural talent for math and others do not.
9. Basic computational skills on the part of the teacher are sufficient for teaching elementary school math.

Science

10. is primarily an abstract subject.
11. is primarily a formal way of representing the real world.
12. is primarily a practical and structured guide for addressing real situations.
13. Some students have a natural talent for science and others do not.
14. A liking for and understanding of students are essential for teaching science.
15. It is important for teachers to give students prescriptive and sequential directions for science experiments.
16. Focusing on rules is a bad idea. It gives students the impression that the sciences are a set of procedures to be memorized.
17. If students get into debates in class about ideas or procedures covering the sciences, it can harm their learning.
18. Students see a science task as the same task when it is represented in two different ways.

SECTION II.

To be good at mathematics [science] at school, how important do you think it is for students to [fill in the blank with each of the items below]?

(A) Not important **(B) Somewhat important** **(C) Very Important**

In Mathematics

19. remember formulas and procedures?
20. think in sequential manner?
21. understand concepts?
22. think creatively?
23. understand math use in real world?
24. support solutions?

In Science

25. remember formulas and procedures?
26. think in sequential manner?
27. understand concepts?
28. think creatively?
29. understand science use in real world?
30. support solutions?

SECTION III.

What is your familiarity with the reform documents?

(A)	**(B)**	**(C)**	**(D)**	**(E)**
Not at all	**Small extent**	**Fairly**	**Moderate extent**	**Great extent**

31. Mathematics standards document (Curriculum and Evaluation Standards for School Mathematics).
32. Science standards document Benchmarks for Science Literacy.
33. Science standards document National Science Education Standards.

SECTION IV.

Please indicate if you use (or would use if you taught mathematics and science) the instructional strategies listed below. **(A) No (B) Yes**

In Mathematics

34. Assisting all students to achieve high standards.
35. Providing examples of high-standard work.
36. Using authentic assessments.
37. Using standards aligned curricula.
38. Using standards-aligned textbooks and materials.
39. Using telecommunication-supported instruction.
40. Making connections with science.

In Science

41. Assisting all students to achieve high standards.
42. Providing examples of high-standard work.
43. Using authentic assessments.
44. Using standards aligned curricula.
45. Using standards-aligned textbooks and materials.
46. Using telecommunication-supported instruction.
47. Making connections with mathematics.

SECTION V

48. If you have taught since graduation, for what duration?
    a. in beginning year b. 1 to 2 years c. 3 to 4 years d. > 4 years
49. If applicable, what grade level are you teaching this year?
    a. 1 or 2 b. 3 or 4 c. 5 or 6 d. 7 or 8 e. other
50. If applicable, are you a specialized teacher (by content)?
    a. yes b. no
51. If you are a specialized teacher, what is your content area?
    a. mathematics b. science c. both mathematics and science d. other

RESEARCH IN
the classroom

Sandi Cooper
Baylor University

Preservice Teachers' Analysis of Children's Work to Make Instructional Decisions

Teaching is an interactive process in which teachers gather information, analyze the results, and construct a response based on this diagnosis (Cooney, 1988). Considering alternatives in constructing a response, that is, making an instructional decision, is of great importance in teaching. How might mathematics teacher educators provide experiences for preservice teachers to begin the development of this skill? In an attempt to determine how these experiences might reveal the level of understanding preservice teachers have in regards to children's mathematical thinking, a study was conducted over three semesters. During the mathematics methods course, preservice teachers were involved in analyzing children's work through the review and discussion of several samples. They were required to determine the error pattern, discuss what might have lead to this misconception, and suggest appropriate instructional strategies that might help this student. Although most preservice teachers could correctly identify the computational error patterns, they had difficulty in determining what might have led to the misconceptions and proposing effective instructional strategies.

How do teachers make instructional decisions? How do they decide what to teach, how, and when to teach it? Traditionally, textbooks and local or state curriculum guides have been the basis for instructional decisions. In addition, teachers' personal experiences (with how they themselves learned math) may greatly impact their own instructional practice. In Liping Ma's (1999) study of elementary teachers' understanding of mathematics, she found that teachers in the United States had the perspective that mathematics is "an arbitrary collection of facts and rules in which doing mathematics means following set procedures step-by-step to arrive at answers" (p. 123).

An important element that is missing in this decision making process is an informed view of children's thinking and learning. Shulman (1987) pointed out that the knowledge base teachers need to teach mathematics should include knowledge of mathematics, knowledge of students, and knowledge of instructional practices. Although most teachers are concerned about children's learning outcomes, very few are prepared to consider the process of learning. Many teachers have not had the opportunity in their teacher preparation programs to experience a process of effectively examining children's work. With a focus on children's thinking, teachers could organize more individualized instruction and maximize learning for all students.

A diagnostic process can provide initial insight into a student's conceptual understanding of mathematics content. Diagnosis is a familiar medical term that refers to a physician's observation of symptoms and an analysis of various indicators that leads to a decision about the cause of the problem. Educators have also used the term diagnosis to refer to the assessment and measurement of strengths and weaknesses in academic performance (White, 1996). Ashlock (2002) emphasized that children's work should be examined diagnostically in which we look for error patterns, hypothesize possible causes, and verify ideas. He further suggested that "a student's paper is sometimes a problem or puzzle to be solved" (Ashlock, p. 13). The National Council of Teachers of Mathematics stated that instruction should incorporate an ongoing analysis of children's learning (NCTM, 2000).

With this in mind, it is important to consider how teachers develop the skill of examining children's work diagnostically. Indeed, significant experience teaching mathematics to children is key in developing a more insightful approach to diagnosis, however, new teachers might benefit from an initial experience and framework from which to build a foundation for this skill.

In an effort to determine how these experiences might reveal the level of understanding preservice teachers have in regards to children's mathematical thinking, a study was conducted over three semesters. This study was designed to determine how experiences with the analysis of children's written work impacted instructional decision-making of preservice teachers.

Review of the Related Literature

According to Cooney (1988), teaching is an interactive process in which teachers gather information,

make a diagnosis, and construct a response based on this diagnosis. Considering alternatives in constructing a response, that is, making an instructional decision, is of great importance in teaching. How might mathematics teacher educators provide experiences for preservice teachers to begin the development of this skill?

The National Council of Teachers of Mathematics emphasizes that having knowledge of childrens' common conceptions and misconceptions about mathematics concepts is an essential skill in teaching (NCTM, 1989, 1991). However, recent studies have shown that preservice teachers' abilities to determine the reasoning behind children's responses were lacking (Ball, 1990; Even & Markovitz, 1995; Even & Tirosh, 1995). Tirosh (2000) recommended that the "major goal in teacher education programs should be to promote the development of prospective teachers' knowledge of common ways children think about the mathematics topics the teachers will teach" (p. 5).

Jacobs and Philipp (2004) suggested that teacher educators use children work samples to facilitate discussion about children's thinking in order to help preservice teachers develop deeper understandings about mathematics, teaching, and learning. Through the examination of and discussion about authentic children's work samples, preservice teachers can gain insight into what it means to know and do mathematics (Timmerman, 2004). In addition, preservice teachers may develop some fundamentals of the knowledge they need for teaching, defined by Hill, Schilling and Ball (2004) as the *mathematical knowledge for teaching* (MKT). This knowledge for teaching differs from mathematical knowledge in that it involves understanding the concepts that generates procedures, performing error analysis to determine student's mistakes, and considering effective instructional options.

Rationale for the Study

For a number of years, I attempted to organize opportunities for preservice teachers in my mathematics methods courses to examine children's work. This effort began with a few class sessions focused primarily on the examination of children's work on computation. At the time, the resources available were limited to examples of computation. After a couple of class sessions, preservice teachers were given an assignment to analyze three sets of children's work and propose possible instructional strategies. Although I attempted to improve the experiences and the assignment each semester, I observed the same patterns emerge in how the preservice teachers responded to this exercise. They could determine the error patterns, but they had difficulty proposing reasonable ideas about misconceptions and offered very limited options for instructional strategies, despite my guidance in class. In an effort to improve my own practice, I decided to conduct a more formal analysis of this experience through the organization of a research study. The study was designed to determine the level of understanding of preservice teachers when analyzing children's work in computation.

Research Questions

With the organization of class experiences and a course assignment related to analyzing children's work, the following research questions were developed to guide the exploration in this study.

1. Can preservice teachers correctly identify the computational error pattern of the children's work samples?
2. In what ways do preservice teachers describe the possible misconception that led to an identified computational error?
3. What kinds of instructional strategies do preservice teachers recommend for remediation?

For three semesters, a similar class activity was implemented and the same course assignment was required of preservice teachers enrolled in their mathematics methods courses. In this particular study, the data was collected from preservice teachers in both the elementary (grades EC-4) and middle school (grades 4-8) mathematics methods courses.

Description of Class Activities and Assignment

During their mathematics methods course, preservice teachers were involved in analyzing children's work through the review and discussion of several samples (samples taken from Ashlock, 2002). They were required to determine the error pattern, discuss what might lead to this misconception, and brainstorm possible instructional strategies that might help this child. After working in small groups, the preservice teachers shared as a whole group for a more in depth discussion.

During the small group work time, I provided guidance as they discussed possibilities and attempted to help them see the connections to other instructional strategies we had discussed in previous class sessions. As each group shared their proposed ideas, other groups offered additional thoughts and I attempted to

provide further guidance, specifically related to instructional strategies.

For a homework assignment, the preservice teachers were given three sets of children's work samples to conduct an analysis and provide responses in a written format. For each set of sample children's work, the preservice teachers were asked to 1) identify error pattern, 2) explain possible reasons for misconception, and 3) describe instructional strategies that might help this student. Figure 1 provides the three sets of student sample work for this assignment (taken from Ashlock, 2002).

Data Collection and Analysis

The homework assignments were collected from preservice teachers in three different semesters and serve as the primary source of data for this study. There were a total of 86 homework assignments collected from a combination of preservice teachers from a middle school methods (grades 4-8) course and an elementary methods course (grades EC-4).

The data was organized into three subsets based on the requirements of the assignment to determine the level of understanding in 1) error identification, 2) perceptions of misconceptions, and 3) recommended instructional strategies. For each subset, the data was analyzed in a different format. To ascertain error identification, each response was simply labeled as correct or incorrect. Although the rationale given for misconceptions could not be distinctly categorized as correct or incorrect (it is important to note that teachers should be encouraged to investigate further to determine misconceptions), these responses were categorized as *reasonable proposed rationale*, *unreasonable proposed rationale* or *no rationale provided*. A *reasonable proposed rationale* purported ideas that directly related to the error pattern or offered specific theories based the child's previous experiences or lack thereof. A response was categorized as an *unreasonable proposed rationale* if it did not provide sufficient information (one sentence or phrase), was too vague or broad, or was simply not related to the child's work.

The recommended instructional strategies were analyzed in three levels with a combination of both a qualitative and quantitative approach. In the first level, the narrative data was analyzed qualitatively to determine emerging themes (Miles & Huberman, 1994). The second level of analysis involved the categorization of each response into these identified themes. For the third level of analysis, a quantitative approach was used to determine the percentages of responses in each theme.

Results

Although the preservice teachers could correctly identify the computational error patterns, they had some difficulty in determining what might have led to the misconceptions and suggesting effective instructional strategies. The overall analysis of the data revealed that most preservice teachers simply choose a basic "reteach" strategy that only allows students to experience the same instructional approach, just at a slower pace.

Identification of Error Pattern

All preservice teachers were able to correctly identify the error pattern in each sample of student work. In sample one, the student was completing two-and three-digit addition problems, but she was adding the columns starting from the left, instead of starting in the ones column. The student in sample two was attempting to complete subtraction problems that required regrouping, but she did not regroup and simply subtracted the larger number from the small number in each column. In sample three, the student had long division problems with one-digit divisors and two- and three-digit dividends, however, when completing the quotients, the student started in the ones column. (See Figure 1 for student samples.)

Perceptions of Misconception

The preservice teachers proposed possible reasons for the misconceptions for three samples of student work. Each response was categorized as a *reasonable proposed rationale*, an *unreasonable proposed rationale*, or *no rationale provided*. With a total of 86 homework assignments, there were 258 total responses that were analyzed. Of these total responses, 206 were identified as a reasonable proposed rationale, 28 were identified as an unreasonable proposed rationale, and 24 did not provide a rationale at all.

For each student sample, an example of a reasonable proposed solution and an unreasonable proposed solution is provided in Table 1.

Some preservice teachers wanted to identify misunderstandings as a sign for a learning disability or dyslexia or they simply stated the student was confused or just didn't understand. However, as indicated by the total numbers, 80% of the preservice teachers provided a reasonable proposed rationale, while only 11% provided an unreasonable proposed rationale.

Name Mary

A.	B.	C.	D.
432	74	385	563
+265	+43	+667	+545
697	18	9116	118

Check to see if you found Mary's pattern by using her erroneous procedure to compute these examples.

E. 254 + 535

F. 618 + 782

Name Cheryl

A.	B.	C.	D.
32	245	524	135
-16	-137	-298	-67
16	112	374	132

Did you find her error pattern? Check yourself by using her procedure for these examples.

E. 458 − 372

F. 241 − 96

Name Gail

A. $2\overline{)88}$ → 44; 8; 8

B. $4\overline{)164}$ → 14; 16; 4; 4

C. $3\overline{)228}$ → 67; 21; 18; 18

D. $5\overline{)465}$ → 39; 45; 15; 15

Did you find the procedure? Check yourself by using the error pattern to compute these examples.

E. $3\overline{)75}$

F. $6\overline{)516}$

Figure 1. Student samples for analyzing student work exercise (samples taken from Ashlock, 2002).

Table 1
Examples of Proposed Rationale for Misconceptions

Student Sample	Reasonable Proposed Rationale	Unreasonable Proposed Rationale
#1	"One reason for this error is because perhaps she is thinking about reading (we read left to right) so she is working the problem left to right, just like she is reading. The second reason for the error is because she does not understand place value."	"The student was probably not listening when the teacher explained how to add."
#2	"I believe the student is doing this because she thinks she has to subtract from the larger number in each column and it does not matter where the larger number is."	"I can't understand why it would be hard to learn that you can carry numbers over from the left."
#3	"She might have this misconception because in addition, subtraction, and multiplication, you start from the right."	"I think she has this misconception because she is just looking for a number to put the divisor into."

Recommended Instructional Strategies

The instructional strategies suggested by the preservice teachers were analyzed qualitatively first to determine emerging themes, organized in groups according to those identified themes, and then a total number for each group was determined. The percentages were calculated and the results are included in Table 2.

As indicated by the results presented in Table 2, most preservice teachers (38%) suggested instructional strategies that focused on procedures or rules. Although there were several who suggested simplifying the problem (20%), the proposed ideas still focused on an instrumental process and did not go into depth about how this might provide an alternative instructional strategy. In addition, 9% suggested a teacher-directed strategy with more of a focus on following the teacher's procedures. In other words, most responses (67%) still focused on simply "reteaching" the students with a more procedural focus. The categories are further explained below with representative quotations from some of the preservice teachers.

Focus on Procedures. In this category, preservice teachers most often recommended that there needed to be a review of the rules or a step by step explanation of the procedures. They used "I" most often, such as "I will show them" or "I will explain the rules." One preservice teacher shared, "I could help the student by giving step by step examples to show him what to do."

Simplify or Decompose Problem. The responses in this category indicated offering a simpler version of the task or breaking down the problem so that students might better understand the "rule" or procedure for the operation. A preservice teacher wrote, "This students needs to be reviewed on the rules and use simpler practice problems to master these rules."

Use Manipulatives with Exploration. There were some responses that suggested using manipulatives, such as base ten blocks, unifix cubes, or the hundreds chart, and offered ideas of how they would allow students to explore further. As illustrated in this response of a preservice teacher, "I would have her use the base ten blocks and allow her to discover that if the number is larger than the number she is subtracting from, she must borrow from the next place value."

Teacher-Directed Instruction. In this category, the responses focused more on the teacher modeling how to follow the procedures for the operation. For example they would suggest, "watch me" or "I will show you how" to complete this problem. One preservice teacher stated, "As a teacher, I would go over many problems with her and explain each time what I am doing to get the answer."

Student-Teacher Interaction. There were a few preservice teachers who proposed to ask the student questions or allow the student to explain their thought processes. One suggested, "I would have the student explain her thought process to me." Another preservice teacher indicated, "Since I am not very sure about how she got her answer, I would like to speak with her and have her explain her reasoning to me."

Use Manipulatives but No Explanation. Responses included in this category "listed" using manipulatives as a strategy, but did not offer any explanation as to how these would be used. One preservice teacher

Table 2
Recommended Instructional Strategies of Preservice Teachers

Emerging Themes	Overall Percentages ($N = 86$)
Focus on Procedures or Rules	38
Simplify or Decompose Problem	20
Use Manipulatives with Exploration	11
Teacher-Directed Instruction	9
Student-Teacher Interaction	8
No Strategy or Limited Suggestions	8
Use Manipulatives but No Explanation	6

shared, "When explaining this, I would probably use base ten blocks to show the carrying process."

No Strategy or Limited Suggestions. There were some responses that offered very limited suggestions or no strategy was listed at all.

Conclusions and Implications

It is important for preservice teachers to better understand computational errors, misconceptions, and student thinking in mathematics in order to organize effective instruction. Certainly, teachers will gain more knowledge as they gain more experiences with children, but experience with analyzing children's work during mathematics methods courses could help to organize this development. Tirosh (2000) suggested that a "general framework related to cognitive processes and sources of misconceptions could support teachers in their attempts to forsee, interpret, explain, and make sense of students' ways of thinking" (p.23).

The results of this study revealed that preservice teachers are able to identify error patterns and can offer reasonable ideas for misconceptions, however, their understanding of possible instructional strategies for the remediation of common errors in computation is primarily focused on procedural methods. Stephens (2006) found that when asked what strategies children might use to solve tasks that are designed to promote relational thinking, most preservice teachers propose strategies involving "arithmetic computation or algebraic manipulation" (p. 266). McLeman and Cavell (2009) suggested that preservice teachers generally come to methods courses with very little teaching experience and might be prone to think in a procedural way, especially based on their most recent experiences in their own mathematics classes. Based on their experiences with a module related to mathematical knowledge for teaching fractions, McLeman and Cavell further purported that this procedural mentality should be challenged by presenting multiple scholarly experiences related to children's thinking.

More in depth learning experiences, focused on children's thinking, during mathematics methods courses could lead to a better understanding and provide preservice teachers with a better framework for identifying important instructional strategies as they begin their first years of teaching. McLeman and Cavell (2009) suggested that mathematics teacher educators consider using group work and video technology that facilitates interactions around course content. McDonough, Clarke, and Clarke (2002) indicated that one-on-one interviews with young children could greatly enhance a teacher's knowledge of a child's conceptual understanding. In a study conducted by Timmerman (2004), preservice teachers had the opportunity to facilitate a structured interview and fraction activity stations. Through this experience, one of the preservice teachers shared the realization that her own mathematical growth and conceptual understanding should come before designing instruction.

Based on the results of this study and further assertions from the literature, mathematics teacher educators should consider these recommendations.

Preservice teachers need more opportunities to:

- analyze children's written work and investigate related thinking processes
- explore mathematics content in more depth in order to develop varied instructional strategies (Ball, 1990; Timmerman, 2004)
- observe children engaged in mathematical activities (Tirosh, 2000)

Tirosh further recommended that more effort should be devoted to the exploration of how teacher education

programs could improve preservice teachers' knowledge of children's ways of thinking. When preservice teachers are involved in opportunities to examine and discuss children's work samples, they gain insight into what it means to know and do mathematics (Timmerman, 2004), and discover more about the knowledge they need for teaching (Tirosh, 2000).

Continued Research

From this initial attempt to encourage preservice teachers to develop a better understanding of the benefits of analyzing children's work, I have revised the class sessions and assignments to focus more on children's thinking. In addition to analyzing children's work, preservice teachers have the opportunity to "catch a glimpse" into the child's thinking through video clips of children providing explanations. In recent years, more resources have become available that has allowed me to incorporate more opportunities for the exploration of children's thinking. The preservice teachers still complete the "Analyzing Children's Work" exercise that was used for this current study, however, I have implemented an additional assignment that includes a one-on-one interview with a child.

The subsequent research study will provide more insight into the impact of these expanded and improved experiences. For further analysis, a random sample of the preservice teachers will be interviewed at the conclusion of their course experiences and during their internship year, after they have had more experiences working with children. Although many preservice teachers at times still rely on a model of traditional, procedurally-focused teaching practices, as evidenced by the results of this study, the implementation of the recommendations could lead to the development of a better foundation for instructional decisions.

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The Quantum Revolution: A Historical Perspective (Greenwood Guides to Great Ideas in Science)
Author: Kent A. Peacock

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Reviewer: Robert J. Whitaker
Missouri State University
Springfield, MO 65897

Toward the end of the Nineteenth Century Newton's mechanics, Maxwell's electrodynamics, and the recently emerging thermodynamics seemed to be providing answers to most of the questions of physics. These approaches to understanding nature had been developed from and applied to macroscopic events, and emphasized a continuity and a determinism in the results. They are often referred to as "classical" physics. The practitioners were confident that their approaches could obtain solutions to new problems (if any) that might confront them.

Lurking in the background, however, were a few problems that had not been satisfactorily explained. Among these were the spectra of elements, the radiation emitted from the so-called "blackbody," and the recently discovered "photoelectric effect." In addition a new phenomenon, that came to be known as "X-rays," was discovered by Roentgen in 1895 and, unexpectedly, "radioactivity" was discovered by Becquerel in 1896.

In 1900 Max Planck suggested that radiation from a black body is not emitted continuously but in discrete packets which he called "quanta." From this assumption he was able to derive a theoretical expression that described the full range of radiation observed from a black body. Subsequently, Einstein used this assumption to explain the photoelectric effect (1905), and Neils Bohr used it to explain the spectra of hydrogen (1913). Each of these, including Roentgen and Becquerel, were to receive the Nobel Prize. As successful as this early "quantum theory" was, it still had roots in classical physics. Soon a more radical break seemed necessary. This was accomplished by Schrödinger's "wave mechanics" and by Heisenberg's "matrix mechanics." While these seemed initially to be very different, they were soon shown to be mathematically equivalent.

From the mid-1920's to mid-1930's this new "quantum mechanics" was used to solve a large number of problems in physics and in chemistry. While it was highly successful in its application, many of its founders debated long and hard over the *meaning* of the theory. The author, a philosopher of science, devotes extensive coverage to this debate and to the meaning of "physical reality" suggested by quantum mechanics. This debate has not subsided and new discoveries bring new issues to the table.

Quantum theory originated in attempting to explain events at the atomic level. More recently it has joined with general relativity (explanation of gravity) to understand cosmology and the physical origins of the universe. It is clear that not all of the problems of physics have been solved as physicists (and cosmologists) work together to find a "theory of everything."

The author has provided the reader with an extensive survey of quantum mechanics in a relatively short space. His writing is clear, but readers with limited background may find it challenging. He provides a useful glossary and comprehensive bibliography at the end. This book should be a useful guide to anyone who wants to extend their understanding of the subject beyond a standard textbook presentation.

PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to: Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel; or fax to:972-86-477-648. Questions concerning proposals and/or solutions can be emailed to: eisenbt@013.net. Solutions to previously stated problems can be seen at: ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before December 15, 2009

5074: *Proposed by Kenneth Korbin, New York, NY*
Solve

$$\sqrt{25+9x+30\sqrt{x}}-\sqrt{16+9x+30\sqrt{x-1}}=\frac{3}{x\sqrt{x}}$$

with x real.

5075: *Proposed by Kenneth Korbin, New York, NY*
An isosceles trapezoid is such that the length of its diagonal is equal to the sum of the lengths of the bases. The length of each side of this trapezoid is of the form $a + b\sqrt{3}$ where a and b are positive integers.
Find the dimensions of this trapezoid if its perimeter is $31 + 16\sqrt{3}$.

5076: *Proposed by M. N. Deshpande, Nagpur, India*
Let a, b, and m be positive integers and let F_n satisfy the recursive relationship

$$F_{n+2}=mF_{n+1}+F_n, \text{ with } F_0=a, F_1=b, n\geq 0.$$

Furthermore, let $a_{n+2}=F_n^2+F_{n+1}^2, n\geq 0$. Show that for every a, b, m, and n,

$$a_{n+2}=\left(m^2+2\right)a_{n+1}-a_n.$$

5057: *Proposed by Isabel Iriberri Díaz and José Luis Díaz-Barrero, Barcelona, Spain*
Find all triplets (x, y, z) of real numbers such that

$$\left.\begin{aligned} xy(x+y-z)&=3,\\ yz(y+z-x)&=1,\\ zx(z+x-y)&=1. \end{aligned}\right\}$$

5058: *Proposed by Paolo Perfetti, Rome, Italy*
Let a,b,c be positive real numbers such that $a + b + c = 1$.

$$\frac{a}{\sqrt{b}(b+c)}+\frac{b}{\sqrt{c}(a+c)}+\frac{c}{\sqrt{a}(a+b)}\geq\frac{3}{2}\frac{1}{\sqrt{ab+ac+cb}}.$$

5079: *Proposed by Ovidiu Furdui, Cluj, Romania*

Let $x \in (0,1)$ be a real number. Study the convergence of the series

$$\sum_{n=1}^{\infty} x^{\sin\frac{1}{1}+\sin\frac{1}{2}+\cdots+\sin\frac{1}{n}}.$$

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IN THIS issue

Research in Brief

Incorporating True Research Opportunities into High School Curriculum: A Research and Design Course

Jennifer Naujock

Field research offers students true scientific practice opportunities and experiences that cannot always be achieved in the classroom. Though research suggests the importance of incorporating field-based research into science curriculum, classroom constraints make it difficult to incorporate true research opportunities into general science courses. This article focuses on the value of incorporating a field based research course offered to all students in science curriculum.

Research Articles

Comparisons of Success and Retention in a General Chemistry Course Before and After the Adoption of a Mathematics Prerequisite

William J. Donovan, Ethel R. Wheland

This study of the relationships between mathematical ability and success and retention in a general chemistry course was conducted at an open-enrollment university whose mission is to provide a quality education to a culturally and economically diverse student body. We studied the correlation between the demonstrated level of mathematical ability and success in chemistry and the correlation between the demonstrated level of mathematical ability and retention in chemistry. After the chemistry department implemented a mathematics prerequisite for the chemistry course, data were examined to compare success and retention prior to and after the adoption of the prerequisite. Analysis showed that success and retention in chemistry increased after the adoption of the mathematics prerequisite.

Graphing Calculator Use in Algebra Teaching

Brenda L. Dewey, Ted J. Singletary, Margaret T. Kinzel

This study examines graphing calculator technology availability, characteristics of teachers who use it, teacher attitudes, and how use reflects changes to algebra curriculum and instructional practices. Algebra I and Algebra II teachers in 75 high school and junior high/middle schools in a diverse region of a northwestern state were surveyed. Forty of the 75 schools (53%) returned a total of 109 individual surveys. Results indicated that: (1) While 78% of teachers have some access to the technology, only 28% use it regularly. (2) Statistically significant relationships exist between use and age, years of experience, teaching assignment, and teaching level. (3) Respondents view graphical solution methods as secondary to symbolic methods. (4) Teachers are more receptive to using technology to supplement rather than expand the curriculum.

Model-Based Inquiry and School Science: Creating Connections

Cynthia Passmore, Jim Stewart, Jennifer Cartier

Much has been made in recent years of inquiry approaches to science education and the promise of such instruction to alleviate some of the ills of science education, yet in some ways this construct is still unclear to many in the field. In this paper we explore one view of inquiry in science that is based on the development, use, assessment, and revision of models and related explanations. Because modeling plays a central role in scientific inquiry it should be a prominent feature of students' science education. We present a framework based on this view that can serve as a guide to curriculum development and instructional decision-making with the goal of creating classroom environments that mirror important aspects of scientific practice. Specifically, the framework allows us to emphasize that scientists: engage in inquiry other than controlled experiments, use existing models in their inquiries, engage in inquiry that leads to revised models, use models to construct explanations, use models to unify their understanding, and engage in argumentation. Here, we discuss how these practices can be incorporated into science classrooms and illustrate that discussion with examples from our research classrooms.

Science Conference Presenters' Images of Inquiry

Thomas R. Koballa, Jr., Michael J. Dias, Jennifer Lance Atkinson

Inquiry-focused professional development and conceptions of inquiry held by eight professional development leaders were investigated within the context of a state science teacher conference. The prominent ses-

sion format involved session leaders modeling classroom experiences. In all sessions, classroom inquiry was portrayed as a teacher-guided activity with the primary goal being to increase motivation for engaging students in classroom inquiry. The leaders' conceptualized inquiry primarily as a teaching approach with various goals, characteristics, and potential barriers. The findings of this study provide evidence of how inquiry, a prominent feature of science education reform, was portrayed in sessions at a conference sponsored by a state affiliate of the National Science Teachers Association and thought about by persons who led these sessions. The findings have implications for teacher learning from conference-based professional development and its potential influence on science teacher thinking and practice.

Exploring Middle School Girls' Science Identities: Examining Attitudes and Perceptions of Scientists when Working "Side-by-Side" with Scientists

Donna Farland-Smith

This article is the culmination of an extensive inquiry-focused interactive experience involving female middle school students and five university scientists, which demonstrated that middle school girls' perception of science and scientists can be successfully improved. The study exposed students to adult professional scientists over a period of a few days in laboratory and field exercises. Based on student journal entries and pictorial illustrations, as well as attitude surveys, the experience resulted in a keen appreciation of the sciences among the majority of participants and both a heightened and broadened awareness of Science as a Human Endeavor. The students' resulting perceptions reinforce the importance for science educators to expose their students to adult professional scientists in order for students, especially female students, to develop a better understanding of science and the role of scientists. Engaging scientists in helping promote science as a positive, exciting and satisfying career goal will help debunk common myths in the minds of young students about science and drive students, especially female students, to consider science careers.

editorial

Robert E. Yager, *Guest Editorial*

The Uniqueness of the National Standards from an STS Perspective

For many of us the National Science Education Standards (NSES) provide a recent document indicating needed educational reforms. Too many active scholars now were not part of the thousands who influenced the make-up and final recommendations that led to the NSES. It may be time now to indicate that most of the recommendations for change cannot be seen in many classrooms across the entire U.S. The NSES were published in 1996 after four years of debate and the expenditure of $7 million. It is unfortunate that there is so little indication of impact at the school level.

Important major visions and ideas in the NSES yet to be realized include:

1. Defining eight facets of content that should be considered in all science classes.
2. Focusing on the *unification* of science concepts and process skills.
3. Recognition of the world view of science (the importance and value of the Social Sciences of Science).
4. The collapse of physics and chemistry into "Physical Science."
5. Focusing on the use of science study for resolving personal and societal problems.
6. Focusing on both Science *and* Technology (i.e., the design world) as a major consideration in place of the typical and exclusive focus on understanding the natural world.

All of these "yet to be" features can be "grouped" as STS initiatives. Each chapter of the NSES ends with a contrasting list of Less Emphasis and More Emphasis conditions. These summaries are too often merely overlooked by persons who have and attempt to use the 262 page booklet! There is more interest for most people in the traditional listing of science concepts and process skills that are suggested for including in course outlines across grade levels.

Do the NSES "Standards" apply equally well for collegiate science teaching? They should! This may be critical as science educators consider the importance of developing scientific literacy for all K-12 students as *the* major goal for school science. This may be appropriate but it should be noted that as much as 80% of the collegiate work for preparing secondary teachers is basic science from discipline-bound science in colleges which is taught by instructors with no experience or course work in science/education per se. And, for even teachers "to be" this experience is provided in but one Methods course in the whole B.S. or MAT program. Does not exemplary *teaching* by teachers deserve more attention and study?

We need more unity of purpose, more people collaborating, more active research undertaken by all professionals. We need "above all" to publicize our successes, our moves to the visions we paid/worked to define in the NSES.

RESEARCH IN
brief

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Incorporating True Research Opportunities into High School Curriculum: A Research and Design Course

Field research offers students true scientific practice opportunities and experiences that cannot always be achieved in the classroom. Though research suggests the importance of incorporating field-based research into science curriculum, classroom constraints make it difficult to incorporate true research opportunities into general science courses. This article focuses on the value of incorporating a field based research course offered to all students in science curriculum.

The National Science Education Standards state that all students need the ability to do scientific inquiry (National Research Council, 1996) and gain the skills of science practitioners. Field-work can provide the opportunity to ask real questions and search for answers (Helms, 1998). This is what science is and what scientists do. Scientists use analysis and problem solving skills in their work. Field based research has the potential to allow students to develop critical thinking and problem solving skills, allowing them to think around barriers ("Science research," 2008; Birnbaum, 2004). Field research is more authentic than what is often offered in a classroom setting because it allows students to gain the ability to work through problems without a predetermined answer. Students need the opportunity to learn and practice these skills and do the work just like scientists.

Just as important as science processing skills are for students to learn, it is also important for students to see that science is about the natural world. Birnbaum (2004) writes that science is about the natural world and that our knowledge historically comes from field observations. Students need more opportunities to experience science as it has been experienced historically. When students lack the opportunity for making field observation, they are missing a vital component of science practice.

When students are exposed to field research opportunities, they benefit in many ways.

Field research opportunities have been shown to have a positive impact on student learning. Student motivation is higher when they are engaged in field research opportunities (Holloway, Rofuth, Todd, Gruner, & Mimo, 1998; Manner 1995). The relevancy of field work also may increase student motivation. Students see field learning as practical learning, rather than "classroom" learning. Students see this type of learning as more relevant, in their mind, than classroom studies (Manner). If students are given the chance to participate in meaningful research that is relevant, they are more likely to see the importance and relevance that science holds in their daily lives.

Students involved in field work also show a gain in self-confidence and a sense of accomplishment and pride in doing original science work ("Science research," 2008; Cunniff & McMillen, 1996). Communication skills and teamwork skills are also enhanced when students have real experiences with scientific research (Cunniff & McMillen). Being involved in scientific research also helps students develop more interest and a more positive attitude about science and careers in science and also gain a more accurate representation of scientists and the scientific community (Abraham, 2002).

The benefits of field research do not stop at individual student learning. Classroom dynamics between and among students and teachers impact teaching and learning in school classrooms. Teachers in one pilot program believed that their field research experience helped to remove social and racial barriers and stereotypes between students and between teachers and students (Holloway et al., 1998). Students that do not excel in traditional science courses may do better when placed in a more exciting field research setting where they are asking questions and finding out how to answer those questions.

With all of these reasons supporting the use of field

research in science classrooms, why isn't it done more often? Classroom constraints make it difficult to incorporate true research opportunities into general science courses. Time is a significant issue in thoroughly incorporating any research project into the classroom curriculum (Holloway et al., 1998). Most science classes are approximately forty minutes long. This is not enough time to achieve the depth of preparation needed for research practice, experimental design, supply organization, and data collection. Birnbaum (2004) also suggests the difficulty in incorporating field research into public school curriculum. Most states have defined learning outcomes and the school curriculum is packed with required knowledge and skills meaning that if new material is to be considered, it must be added thoughtfully. Field research takes time. The answer and the path are not predetermined. The pressure of providing students with enough content knowledge in general science courses is too much for many teachers to take time to perform real research opportunities during class time. Field research lends itself to specialized scientific knowledge, rather than general content knowledge (Holloway et al.).

Support is another reason why incorporating field research in the classroom can be difficult. In many successful programs a scientist was available every step of the way to assist teachers in implementing their research projects into the classroom. Holloway et al. (1998) describe a field research program incorporated into schools in which teacher participants cite that most teachers would have difficulty incorporating the field research project without a supporter.

One final reason why teachers do not incorporate field research in the classroom is because they do not know how to do it (O'Neal, 2003). Teachers often do not have the skills or training necessary to teach research skills to others. Not only does field research require strong content knowledge, but it also requires those skills that we expect our students to learn: questioning, experimental design, formulating scientific explanations, and good problem solving skills. Until teachers are comfortable with field research situations, their fear of the unknown will hold them back. The only treatment for this problem is experience.

A separate, independent field research course should be included in science curriculum requirements for all students to participate in. It takes more than one or two research opportunities to become knowledgeable about the nature of science. Administrators need to assist in facilitating partnerships between experienced local scientists and teachers. This provides a support for the classroom teacher, as well as a guide for conducting meaningful research. Research skills must be a priority for students' education. Field research offers true scientific practice opportunities and experiences that cannot always be achieved in the classroom.

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Comparisons of Success and Retention in a General Chemistry Course Before and After the Adoption of a Mathematics Prerequisite

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This study of the relationships between mathematical ability and success and retention in a general chemistry course was conducted at an open-enrollment university whose mission is to provide a quality education to a culturally and economically diverse student body. We studied the correlation between the demonstrated level of mathematical ability and success in chemistry and the correlation between the demonstrated level of mathematical ability and retention in chemistry. After the chemistry department implemented a mathematics prerequisite for the chemistry course, data were examined to compare success and retention prior to and after the adoption of the prerequisite. Analysis showed that success and retention in chemistry increased after the adoption of the mathematics prerequisite.

In the mid-1990s, our university and its department of chemistry began to increase its efforts to attract more students to STEM (science, technology, engineering, and mathematics) fields of study and to give recruited students every opportunity to succeed. The general chemistry course, Principles of Chemistry I, was seen as fundamental to the effort, so the chemistry department hired a chemical education specialist, whose duties included coordination of the freshman chemistry program and research in chemical education. She and her successor were chosen in part because of their understanding of the need for sound pedagogical practices in the chemistry classroom. The freshman chemistry courses, including Principles of Chemistry I, implemented innovative approaches to the teaching of chemistry: clicker technology (Donovan, 2008), peer tutors (Engle, Donovan, Hollinger, & Monroe, 2007), web-based tools for problem-solving and written homework (Burdge, 2001), online homework and tutorials (Donovan, 2007), efforts to model good teaching methods for future teachers, development of standards-based lesson plans, involvement in professional development for high-school and middle-school chemistry teachers (Donovan, Calvo, Horvath, Turner, & Williams, 2007), more active presence in university recruitment, organization of chemical education symposia at national meetings, and authorship of textbooks and supplementary materials (Brown, LeMay, Bursten, & Burdge, 2003; Burdge, 2009). The department has encouraged both the implementation and the study of these innovations and activities.

Principles of Chemistry I is a general chemistry course intended for science and engineering majors and preservice secondary school science teachers. It is a prerequisite for the second semester of general chemistry, and addresses all of the chemistry content required by the state Board of Regents for transfer credit consideration (Ohio Board of Regents, n.d.). The Board of Regents lists proficiency with algebra as a prerequisite for such a course, and students' competencies by the completion of the chemistry course are expected to include "sufficiently strong analytical and interpretative skills to effectively apply algebraic methods to solve problems" (Ohio Board of Regents). These algebraic methods might involve using and understanding scientific notation, unit analysis, symbol manipulation, negative exponents, and radical expressions; setting up, graphing, and solving equations; representing functions verbally, graphically, and algebraically; using functions that are constructed as models of real-world problems; and an understanding of direct and inverse proportions. Examples of mathematics that science students should use and understand are described in the National Science Education Standards (National Research Council [NRC], 1996).

The student population in Principles of Chemistry I is composed primarily of freshmen who are required to take the course to satisfy a requirement for their intended major (e.g., science, engineering, secondary education). Few, if any, students take the course entirely as an elective. The criteria for admission to the university do not necessarily include the completion of a chemistry course in high school, so the students in Principles of Chemistry I may or may not have done

Table 1
Spring 2003 Principles of Chemistry I Students' Responses to Survey Question

	N	Would help a lot	Would help a little	Would make no difference	Would hurt a little	Would hurt a lot
Chemistry Repeaters	28	4 (14%)	10 (35%)	13 (46%)	1 (3%)	0 (0%)
Chemistry First-time Takers	55	7 (13%)	12 (22%)	30 (55%)	2 (4%)	4 (7%)
Total	83	11 (13%)	22 (27%)	43 (52%)	3 (4%)	4 (5%)

so. Thus, the course is taught under the assumption that students are seeing the chemistry material for the first time.

At the time this study began, there were no departmental or university prerequisites for students enrolling in Principles of Chemistry I. Anecdotal evidence from students who had not successfully completed the course suggested that a lack of mathematics skills had contributed to their poor performance in chemistry. To check the veracity of the anecdotal evidence, the ACT mathematics scores of students in Principles of Chemistry I were examined. Because most of the students enrolled at the university had taken the ACT exam in high school, it was reasonable to use ACT score data. Data from two fall semesters (2001 and 2002) were analyzed separately, and the results indicated that the anecdotal evidence had some validity. Figure 1 displays the strong correlation between failure/withdrawal rates and the ACT mathematics scores for students enrolled in the course in Fall 2001 ($N = 494$).

At the end of Spring 2003, a survey was administered to students in Principles of Chemistry I. On one question, students were asked "How do you think having a mathematics prerequisite/corequisite for registration in this course would affect your experience in this course?" Nearly 38% of the respondents stated that a mathematics prerequisite/corequisite would have positively affected their chemistry course experience (Table 1).

The combination of anecdotal evidence, analysis of Fall 2001-2002 data, and the Spring 2003 survey led the first author to do a preliminary study on the impact of a certain level of mathematical ability, as measured by scores on standardized college entrance exams or by successful completion of a university mathematics course, on the success rate of students enrolled in Principles of Chemistry I. The majority of students in Principles of Chemistry I had an ACT mathematics score, so the preliminary study focused on that information, although the findings also held for students who had an SAT score. Although fewer students had successfully completed a university mathematics course prior to enrolling in chemistry, the number was large enough to also consider successful completion of a prior mathematics course as a measure of mathematical ability. Our research questions in the following study were:

1. Does a demonstrated level of mathematical ability correlate with success and/or retention in Principles of Chemistry I?

2. Were student success and/or retention in Principles of Chemistry I changed after the adoption of a mathematics prerequisite?

Theoretical Framework/Literature Review

We began by reviewing the literature on the connection between success in mathematics and science and success in chemistry. Several studies over the years in *School Science and Mathematics* dating as far back as the 1920s (Clark, 1938; Lamb, Waggoner, & Findley, 1967; Ogden 1976; Powers, 1921; West, 1932) investigated and reported the connection between student achievement in high school science and success in college chemistry.

Hovey and Krohn (1958, 1963) described a pre-testing program to predict success or failure in the first semester of general chemistry which became known as the Toledo Chemistry Placement Exam. In part, the Toledo exam tested arithmetic and algebra skills, but to a much smaller extent than chemistry content. Russell (1994) described the California Chemistry Diagnostic Test, which also primarily tests chemistry content (37 chemistry questions, 7 mathematics questions) but is designed as a diagnostic tool rather than a placement tool.

Investigating the relationship between SAT mathematics scores and chemistry course final grades, Pickering (1975) asserted that "there is an overwhelming correlation between whatever the math SAT measures

and successful achievement in chemistry.... The math SAT is still a good way to sort out students who are likely to have trouble in freshman chemistry" (p. 512-513). Pickering described an intervention which consisted of a supplementary chemistry course for the students identified from their SAT mathematics scores as being at risk of failure in chemistry. However, Pickering found that "while the supplementary course helps in the short term, it does not do much in the long term" (1977, p. 434).

Ozsogomonyan and Loftus (1979) reported an analysis of five predictors of grades in freshman chemistry, two of which were algebra pretest scores and SAT mathematics scores. Of the predictors investigated, the SAT mathematics score had the highest correlation with final chemistry course grade. High school chemistry experience was considered as well, and it was observed that the withdrawal rates from freshman chemistry were significantly higher for those students without high school chemistry than for those with high school chemistry.

Spencer (1996) reported a high correlation between SAT mathematics scores and freshman chemistry grades. He commented that freshman chemistry students need to recognize the importance of mathematical skills, noting that "it would be worthwhile to determine if mathematics courses might increase the probability of achieving higher chemistry grades" (p. 1152). Chambers and Blake (2007) described a multivariate analysis for predicting student success in general chemistry and reported that they attained nearly 90% accuracy in placement using high school class rank, Toledo placement exam score, and ACT/SAT mathematics score together to give a composite predictor of success in general chemistry.

Bohning (1982) described one of the few analyses of a mathematics intervention, a noncredit course, Basic Mathematics for Introductory Chemistry, offered for 1 week before the beginning of the semester. The remedial mathematics course was an approach "aimed specifically at mathematical deficiencies... and based on the premise that the deductive reasoning process which accompanies basic mathematical technique is crucial for a meaningful comprehension of general chemistry principles" (p. 207). Genyea (1983) described a preparatory chemistry course which emphasized problem solving using an approach that included mathematical underpinnings.

Pienta, Thorp, Panoff, Gotwals, and Hirst (2001) and Pienta (2003) described a placement examination and Internet-based mathematics tutorial for freshman chemistry. The tutorial and self-assessment materials were intended for asynchronous use as a review of mathematical concepts and skills for students enrolled in the first semester of freshman chemistry.

Tai, Sadler, and Loehr (2005) reported on factors influencing success in general chemistry, and SAT mathematics score and last high school mathematics grade were the two influential predictors of success in chemistry. Tai, Ward, and Sadler (2006) found that the same two factors along with enrollment in high school calculus were strong and statistically significant predictors of success in college chemistry.

In light of this research showing the positive impact of strong algebra skills on chemistry grades, and in light of the fact that our university is an open-enrollment university with minimal mathematics skills required for admission, the chemistry department realized that its efforts to promote student success such as use of clickers, peer tutors, and online homework might not have the desired impact on success rates if students in the class did not have appropriate mathematics skills. Thus it was decided to examine whether or not a prerequisite in mathematics should be part of the Principles of Chemistry I course.

Design and Analysis

After evaluating the anecdotal information, the Fall 2001 and 2002 ACT data, and the 2003 survey results, the department decided to analyze comprehensive student data for Principles of Chemistry I for the periods of Fall 2001-2005 and Spring 2002-2006. These data convinced the department and university that a mathematics prerequisite should be put in place beginning in Fall 2006. Data for students in the chemistry course in Fall 2006-2007 were collected and analyzed to compare student success before and after implementation of the prerequisite.

Research Question 1: Does a demonstrated level of mathematical ability correlate with success and/or retention in Principles of Chemistry I?

In order to examine Research Question 1, we first obtained data on students who were enrolled in Principles of Chemistry I during the fall semesters of 2001 through 2005 (N=2949). For our analysis of success rates in chemistry, we studied only those students who completed the course with a final grade of A through F (N=2495), excluding data for students who officially withdrew from the course, because of the many confounding factors that contribute to decisions to with-

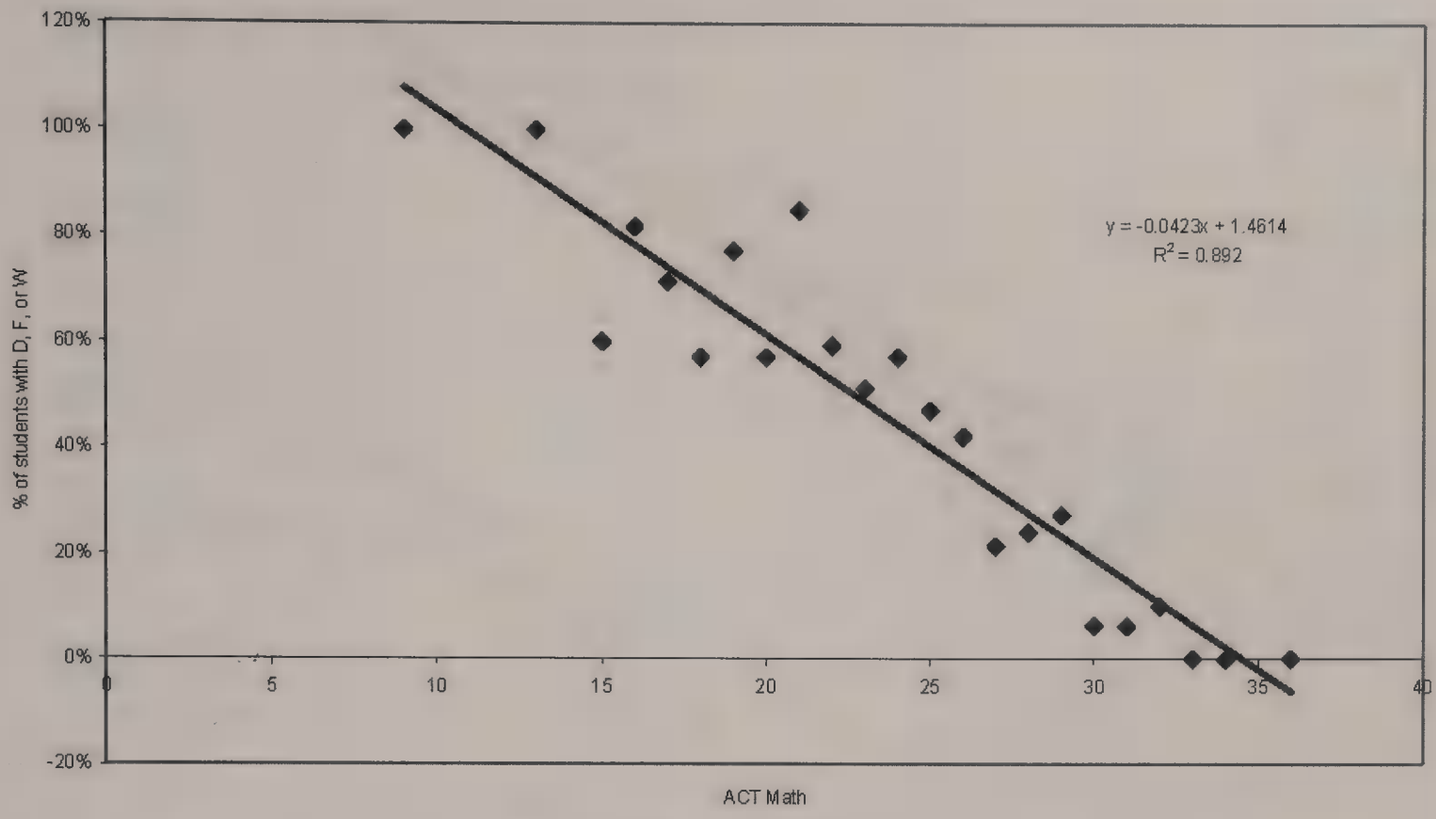

Figure 1. Chemistry failure/withdrawal rate vs. ACT mathematics score, Fall 2001.

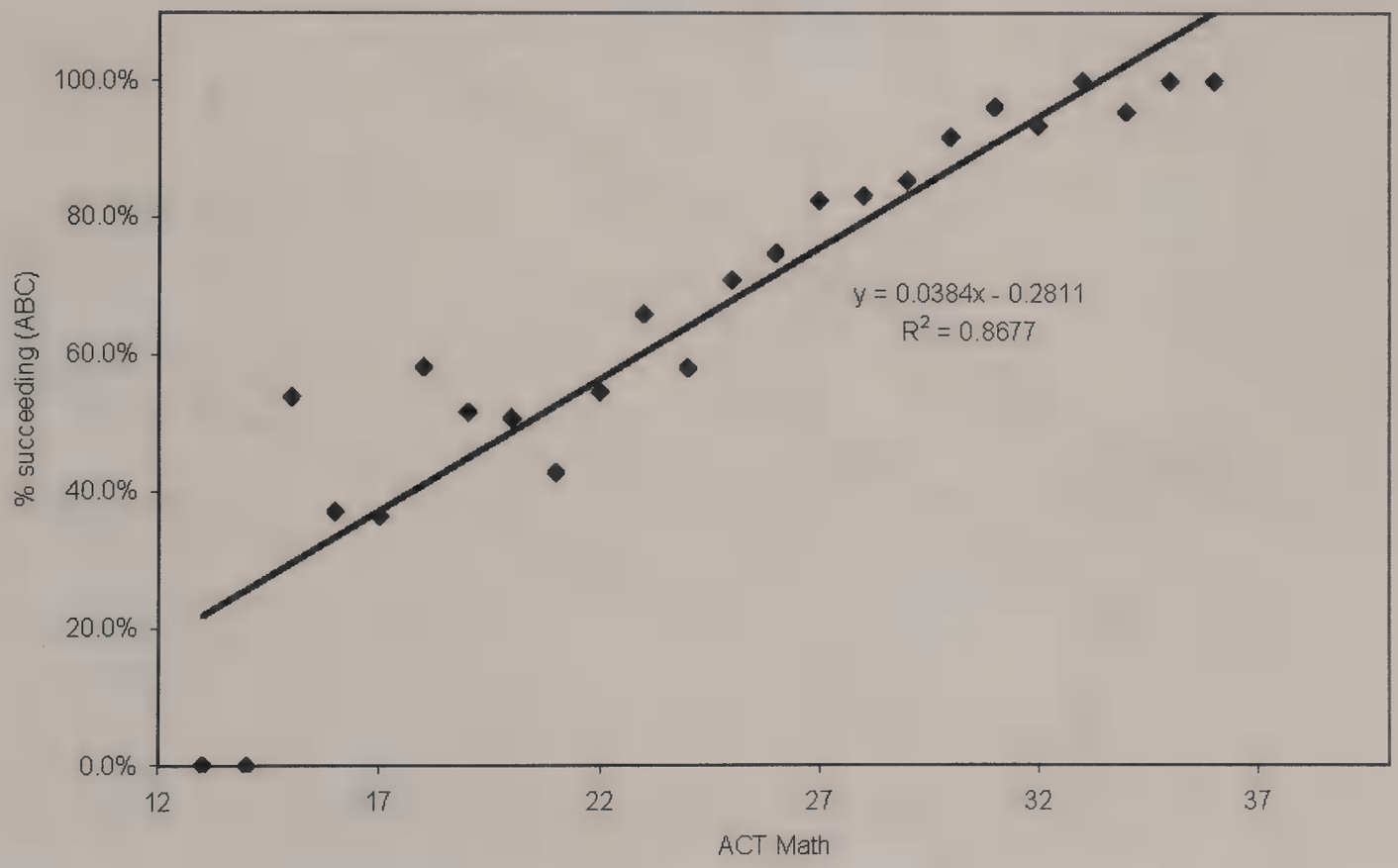

Figure 2. Student success in chemistry vs. ACT mathematics score, 2001-2005 Fall semesters (excluding students who withdrew from course).

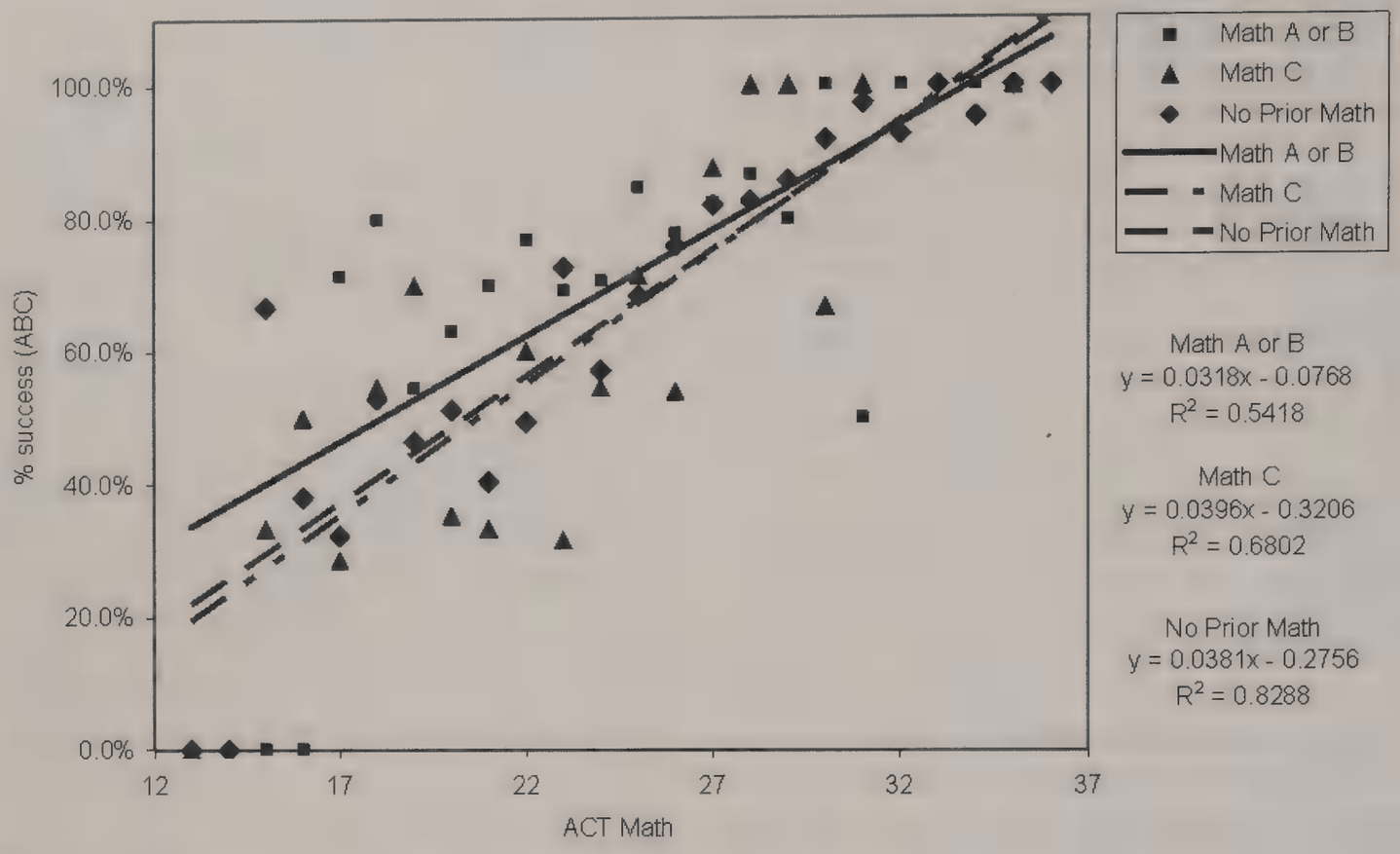

Figure 3. Student success in chemistry vs. ACT mathematics score, 2001-2005 fall semesters: A/B in Math vs. C in Math vs. No Math (excluding students who withdrew).

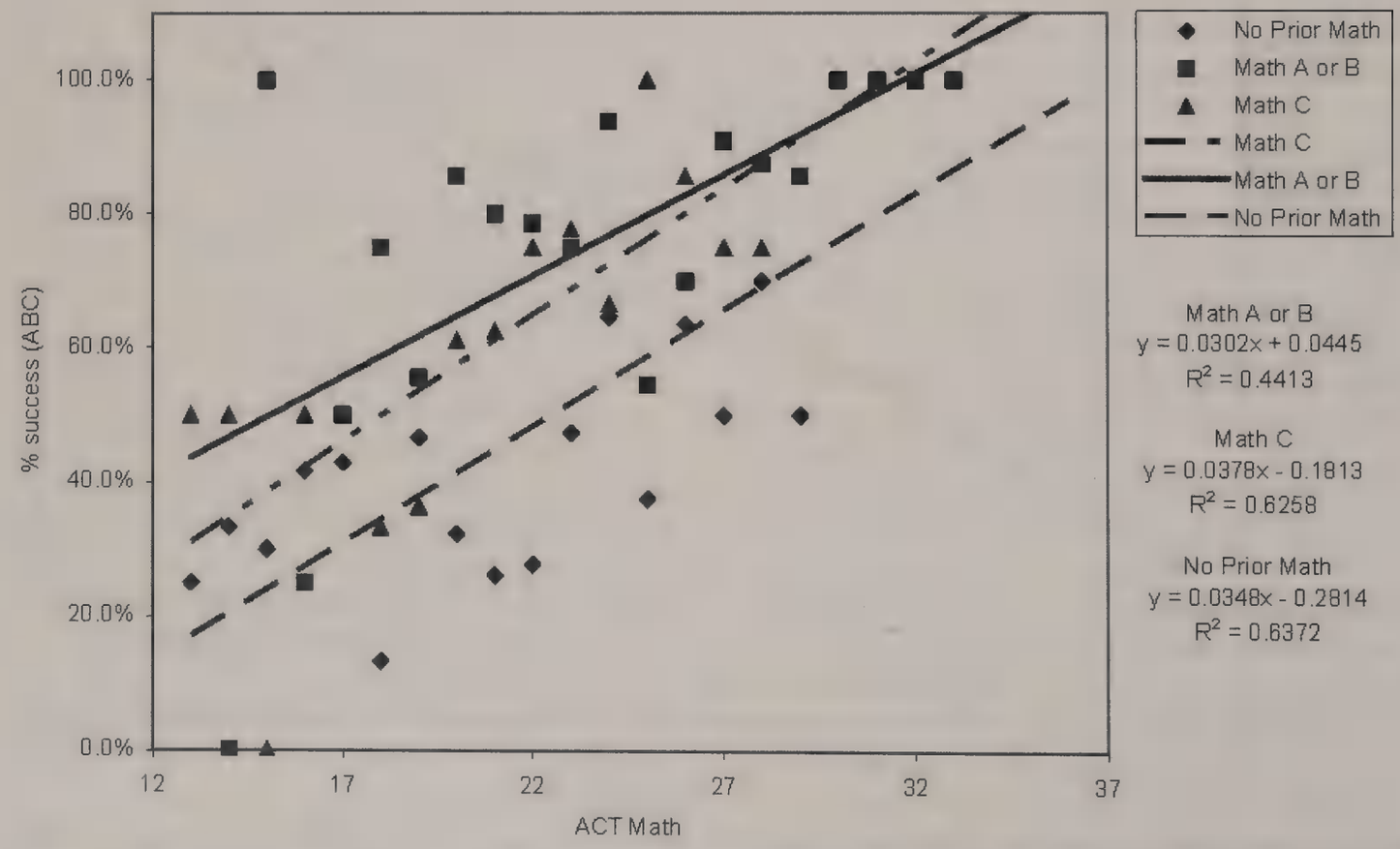

Figure 4. Student success in chemistry vs. ACT mathematics score, 2002-2006 spring semesters: A/B in Math vs. C in Math vs. No Math (excluding students who withdrew).

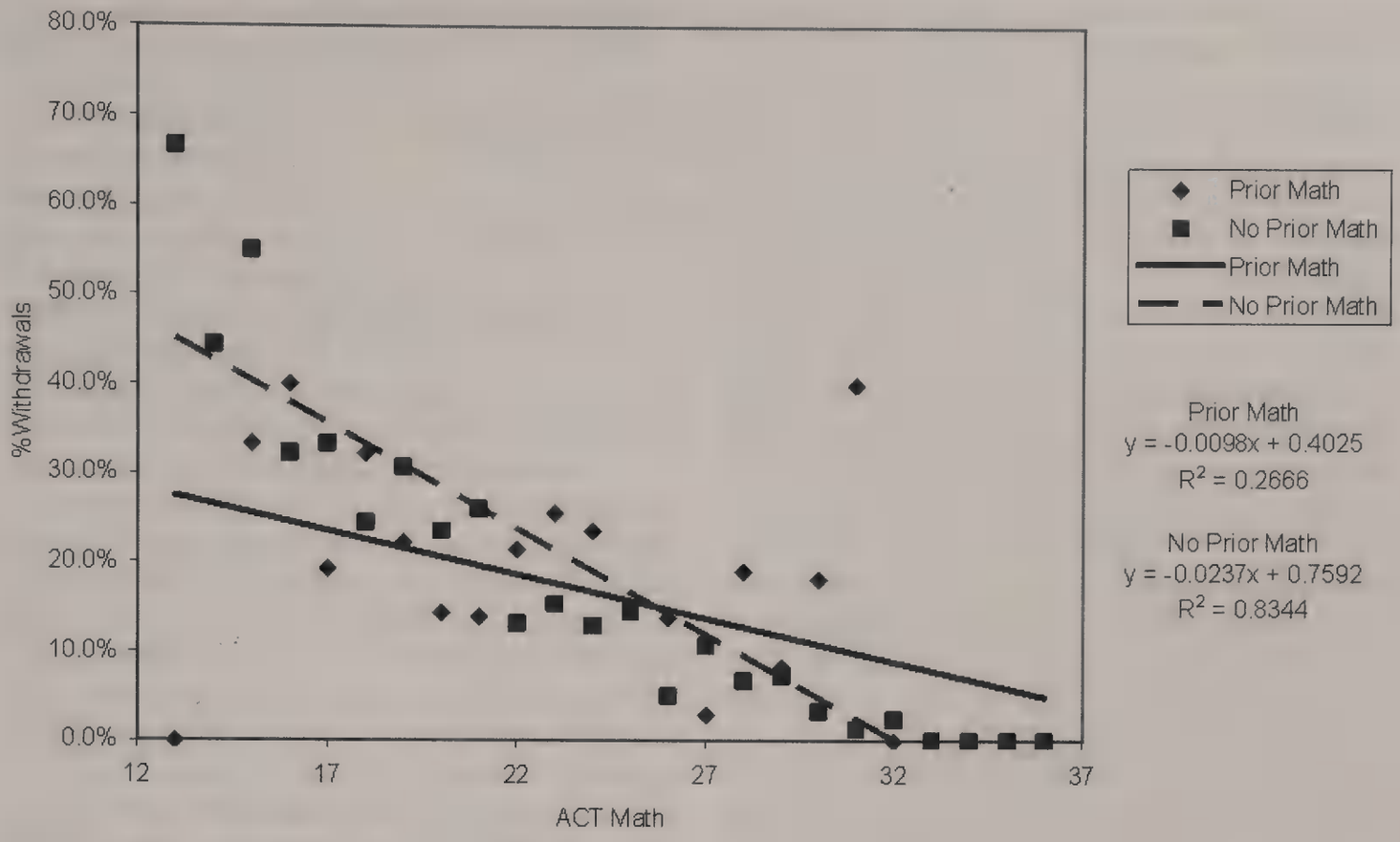

Figure 5. Student withdrawal rates from chemistry vs. ACT mathematics score, 2001-2005 fall semesters.

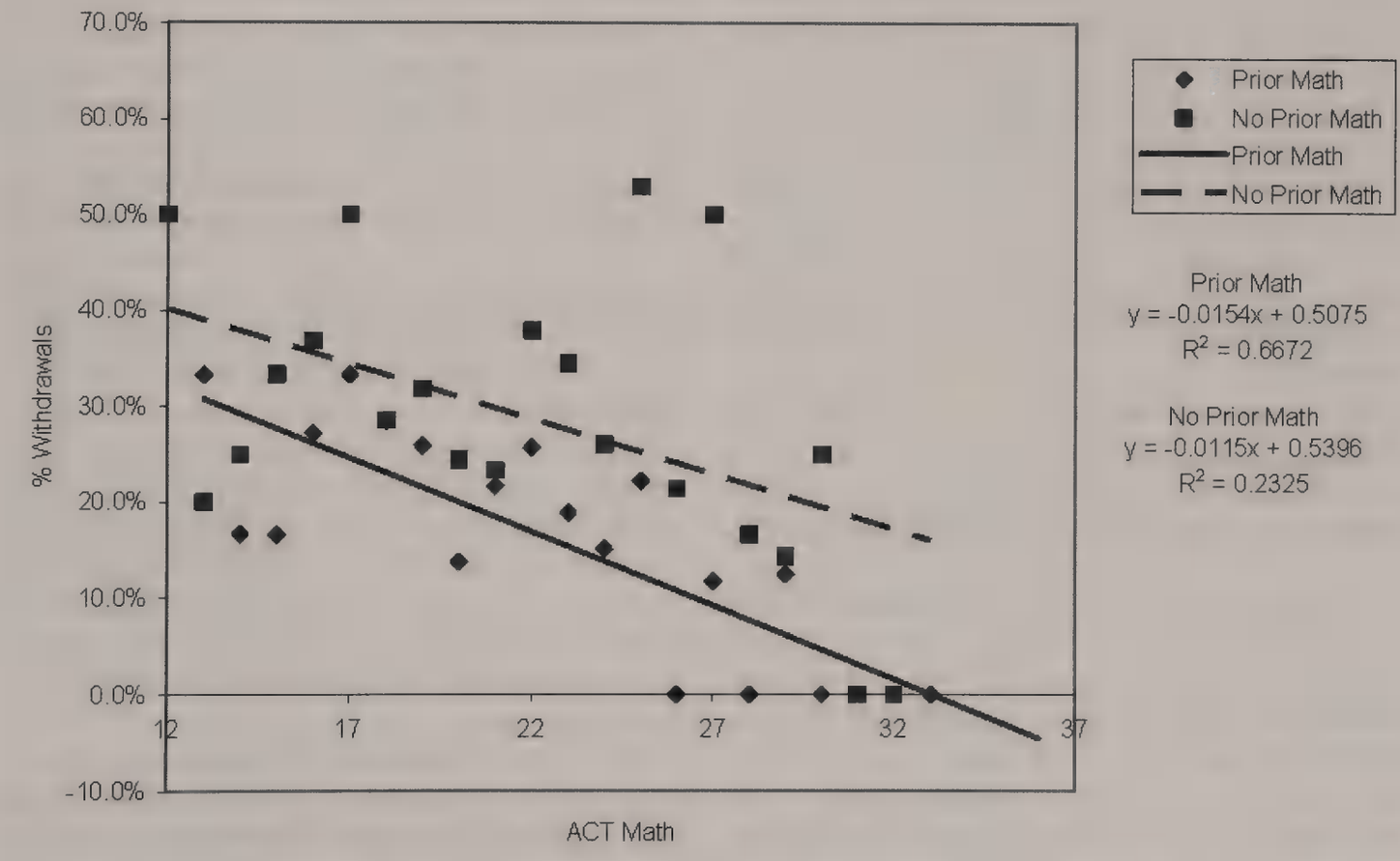

Figure 6. Student withdrawal rates from chemistry vs. ACT mathematics score, 2002-2006 spring semesters.

draw. The data for students who withdrew were analyzed separately with respect to retention in the course.

The aggregate data from the five fall semesters confirmed that ACT mathematics scores correlate strongly with success in chemistry (Figure 2). Approximately 37% of the group with ACT mathematics scores of 17 succeeded in chemistry, whereas 75% of the group with ACT mathematics scores of 26 succeeded in chemistry.

Starting with the same data set as described above, we selected those students who completed Principles of Chemistry I and who also completed a prior college-level mathematics course with a final grade of C or better. Successful completion of College Algebra (the mathematics course before Precalculus Mathematics in the mathematics sequence) or a higher mathematics course was chosen as the criterion for "completion of a prior mathematics course." This precluded the inclusion of developmental or introductory mathematics courses as "prior mathematics" for our purposes.

We categorized the data for students who succeeded in prior mathematics courses by the final letter grade they received, considering students with an A or B separately from those who earned a C. We compared both groups to a third group of students: those who did not, as defined above, complete a prior mathematics course (i.e., those who took no mathematics course at all, those whose highest-level mathematics course was below College Algebra, and those who did not earn at least a C in College Algebra or a higher-level mathematics course).

As shown in Figure 3, earning an A or B in the prior mathematics course was correlated with a higher success rate in chemistry than earning a C in the prior mathematics course. In addition, earning a grade of C in the prior mathematics course corresponded to virtually the same success rate in chemistry as not taking any prior mathematics course or failing to complete the mathematics course with a C or higher. For example, students with a ACT mathematics score of 15 and a prior mathematics grade of A or B are predicted to have a 40.0% success rate in chemistry, whereas students with the same ACT mathematics score and a prior mathematics grade of C have a predicted 27.3% success rate, similar to the 29.6% success rate predicted for those with no prior mathematics. Figure 3 also shows that the difference in success rates in chemistry between those with an A or B in mathematics and those with a C in mathematics is largest for those most at risk to fail chemistry, those with the lowest ACT mathematics scores (see Figures 1 and 2).

We performed the same analysis on the data for students who were enrolled in Principles of Chemistry I during the spring semesters of 2002 through 2006 (N = 902). As was done for the fall semester data, we excluded data for students who officially withdrew from the course, studying only those students who completed the course with a final grade of A through F (N = 674). Figure 4 shows that the differences in chemistry success rates related to final grade and/or completion of a mathematics course are more pronounced in the spring semesters than in the fall semesters. At all ACT mathematics scores, the success rate in chemistry for students with a grade of A or B in mathematics is higher than that of those with no prior mathematics course. The success rate in chemistry of those students earning a C in mathematics is also higher than that of those with no mathematics, but is lower than that of the A/B group in the low ACT mathematics score range, where students are at greater risk of failure in chemistry.

We also analyzed the aggregate data for the fall semesters of 2001-2005 for those students who officially withdrew from Principles of Chemistry I and thus were excluded from the analysis above. We separated this population into two subpopulations: those with a prior college-level mathematics course and those without a prior college-level mathematics course (as defined above). Figure 5 shows that at the lower end of the ACT mathematics score scale, where students are at greater risk of failure in chemistry, the withdrawal rate of those with no prior mathematics course is higher than that of students with a prior mathematics course. So many confounding factors in why students choose to drop the chemistry course make it impossible for us to draw any conclusions from this observation, however. (Note that the R^2 for the group with prior mathematics courses is much lower than that for the group without mathematics courses, suggesting confounding factors are present.) The same analysis was performed on data for students withdrawing from the chemistry course in the spring semesters of 2002-2006. Figure 6 shows these results, which are consistent with those of the fall semesters.

The results of the analysis of success rates and withdrawal rates in Principles of Chemistry I from the fall and spring semesters led to the formulation and adoption of a mathematics prerequisite for Principles of Chemistry I. As stated in the official course description, a student must be eligible to take Precalculus

Mathematics (or a higher-level mathematics course) in order to register for Principles of Chemistry I. This eligibility may be established by successful completion of the College Algebra course with a grade of C or higher, an ACT mathematics score of 24 or higher, an SAT mathematics score of 560 or higher, or an appropriate mathematics placement test score. With the implementation of the prerequisite at the beginning of Fall 2006, we were able to formulate and study our second research question.

Research Question 2: Were student success and/or retention in Principles of Chemistry I changed after the adoption of a mathematics prerequisite?

In order to examine Research Question 2, we first obtained data on students who were enrolled in Principles of Chemistry I during the fall semesters of 2006 and 2007 ($N = 1288$). For our analysis of success rates in chemistry, we studied only those students who completed the course with a final grade of A through F ($N = 1166$), excluding data for students who officially withdrew from the course, again because of the many confounding factors that contribute to decisions to withdraw. The data for students who withdrew were analyzed separately with respect to retention in the course.

We analyzed the Fall 2006-2007 success rates in chemistry for two groups of students. The first group ($N = 1092$) included those who had met the newly established prerequisite for the chemistry course through their ACT mathematics score or SAT mathematics score or by successful completion of a college-level mathematics course at the university; the second group ($N = 196$) included those who established mathematical ability by transfer credit from outside the university or from the university's community and technical college, by course work completed before changing majors, or by score on the university's mathematics placement exam. The chemistry course success rates of the two groups were virtually identical (76.4% and 75.3%), as shown in Table 2.

Since our goal was to determine if student success rates had changed since the adoption of the prerequisite, we revisited the Fall 2001-2005 student data. We sorted the students into two groups based on the same criteria as described for Fall 2006-2007; however, the second group in Fall 2001-2005 contained not only the students who would have established mathematical ability by transfer credit from outside the university or from the university's community and technical college, by course work completed before changing majors, or by score on the university's mathematics placement exam, but also the students who had not established any level of mathematical ability by any measure used by the university, who at the time were able to self-place into the chemistry course. Table 2 shows that students in Fall 2001-2005 who would have met the prerequisite by ACT, SAT, or prior university mathematics course (had it been in place) had nearly the same success rate (74.9%) as both groups of students in Fall 2006-2007, while students in Fall 2001-2005 who would not have met the prerequisite by ACT, SAT, or prior university mathematics course had a much lower

Table 2

Comparison of Fall-Semester Student Success Rates Since and Prior to Implementation of Mathematics-Related Prerequisite for Chemistry

	Fall 2006-2007		Fall 2001-2005	
Met prerequisite by ACT, SAT, or prior mathematics course?	Did meet	Did not meet	Would have met	Would not have met
N	1092	196	2040	909
Students completing course	1005	161	1801	694
Students successfully completing course	768	121	1349	394
% of students successfully completing course	76.4%	75.3%	74.9%	56.8%

success rate (56.8%).

To answer research question 2 with respect to retention in chemistry, we performed the same type of analysis as above on data for students who had officially withdrawn from the chemistry course (Table 3). Among students taking chemistry after implementation of the prerequisite, 8.0% of those who met the prerequisite by ACT, SAT, or prior university mathematics course withdrew from chemistry, compared to a withdrawal rate of 17.9% for those who met the prerequisite by other means. Among students who took the chemistry course before implementation of the prerequisite, 11.7% who would have met the prerequisite by ACT, SAT, or prior university mathematics course withdrew, compared to a withdrawal rate of 23.7% for those who either would have met the prerequisite by other means or would not have met the prerequisite at all.

Of the 909 students who took the chemistry course before the prerequisite was in place and who would not have met the prerequisite had it been in place at the time, 101 students had successfully completed a developmental mathematics course as their only mathematics course prior to enrolling in chemistry. The outcome: 36 students (35.6%) withdrew from chemistry; of the remaining 65 students, 33 students (50.8%) successfully completed chemistry with a grade of A, B, or C while the rest earned a D or F. This withdrawal rate is much higher than that of the other groups, while the success rate is much lower.

Discussion

Even with the innovative approaches to attract and retain students in the university's general chemistry course and to make their experience a worthwhile and successful one, the number of students who did not succeed either by withdrawal or by earning a low grade continued to be unacceptable to the department. It had already been established in the literature that standardized mathematics test scores are good predictors of success in chemistry, and this prompted the department to conduct a study to see if a mathematics prerequisite which would include standardized mathematics test scores would increase success. Our research showed that successful completion of a prior college-level mathematics course was positively correlated with success in the general chemistry course, and the study suggests that completion of a prior mathematics course corresponds to greater retention in the chemistry course.

The first part of this study was presented to the chemistry department faculty as evidence of the need for a mathematics prerequisite for general chemistry. The data indicated that a student with an ACT mathematics score corresponding to placement into the Precalculus Mathematics course was more likely to succeed than to fail in chemistry. Thus the department decided upon a prerequisite equivalent to successful completion of College Algebra, the mathematics course before Precalculus, effective starting in Fall 2006. As mentioned above, the prerequisite may be met through successful completion of College Algebra with a grade of C or higher, an ACT mathematics score of 24 or higher, an SAT mathematics score of 560 or higher, or an appropriate mathematics placement test score. Because of equivalency of courses among various members of the state's university system, eligibility to take chemistry could also be established via transfer credit from another institution; a small percent-

Table 3
Comparison of Fall-Semester Withdrawal Rates Since and Prior to Implementation of Mathematics-Related Prerequisite for Chemistry

	Fall 2006-2007		Fall 2001-2005	
Met prerequisite by ACT, SAT, or prior mathematics course?	Did meet	Did not meet	Would have met	Would not have met
N	1092	196	2040	909
Students withdrawing from course	87	35	239	215
% withdrawing from course	8.0%	17.9%	11.7%	23.7%

age of students are enrolled in the course this way.

The second phase of this study involved the analysis of the differences between student success and retention before and after the implementation of the mathematics prerequisite for chemistry. It can be observed (Table 2) that since the implementation of the prerequisite, most students establish eligibility to enroll in chemistry by either an ACT mathematics score, an SAT mathematics score, or successful completion of a prior mathematics course at the appropriate level. Those students who establish eligibility to take chemistry via mathematics placement exam score or other means such as transfer credit equivalency and who remain in the course do succeed at a comparable rate to those students with the more common prerequisites, but a larger percentage of these students withdraw from the course (Table 3). This suggests that both the prerequisite established by the chemistry department and the alternate prerequisite effectively promote success of students who remain in the course, but the chemistry department's prerequisite is more effective in promoting retention.

When we reexamined the Fall 2001-2005 student data through the lens of the new prerequisite that had not been in effect during that time period, we found further justification for the mathematics prerequisite for chemistry. Of the 909 students who entered the chemistry course in Fall 2001-2005 who would not have met the chemistry department's prerequisite, only 394 successfully completed the course. The other 515 either withdrew from or failed the course. Of course, some of the 909 students had no demonstration of mathematics ability while others would have met the new prerequisite by the above-mentioned alternate means, but there was no control or screening of the students at that time. In this day of needing more people educated in the STEM disciplines, it is not a valid option to compromise the integrity of the standards of the chemistry course; thus some screening of students, even in an open-enrollment university, is justified if one is concerned about student success and retention.

Implications

Our study of the prerequisite implemented in Principles of Chemistry I showed that student success in chemistry was positively correlated with the departmental prerequisite for the course (ACT mathematics score, SAT mathematics score, or successful completion of college algebra or a higher mathematics course). There are alternative ways to meet the prerequisite, such as transfer equivalencies. The departmental prerequisite addresses success and retention in the course reasonably well, whereas students who met the prerequisite in alternative ways were somewhat more likely to withdraw from the course. Thus, in implementing a prerequisite, use of a nationally-normed standard should be considered. A reliable quantitative measure is more effective as a prerequisite than methods such as determining transfer course equivalencies from other universities, perhaps because it is more objective. Our results also suggest that a possible intervention is to suggest to students with weak mathematical ability (as demonstrated by low ACT mathematics scores) who want or need to take chemistry that they complete a college-level mathematics course with a final grade of A or B.

An effective placement tool should measure the prerequisite knowledge that is deemed important for success in the course. Our study has shown that mathematics knowledge at the college algebra level is a contributor to success in chemistry. This is consistent with the National Science Education Standards' call for less treatment of sciences as isolated from other subjects, and more connections between science and other subjects such as mathematics (NRC, 1996, p. 224). "School science and mathematics programs should be coordinated so that students learn the necessary mathematical skills and concepts before and during their use in the science program" (NRC, p. 214). The Standards list numerous specific examples of mathematics that science students need to use and understand, e.g., "understanding connections within a problem situation, its model as a function in symbolic form, and a graph of that function, and using functions that are constructed as models of real-world problems" (NRC, p. 219).

Program goals such as increased student success and retention will not be met just by putting a prerequisite in place, though. Student learning styles, use of peer tutors (Engle et al., 2007), appropriate uses of technology such as "clickers" (Donovan, 2008), web-based tools for problem-solving and written homework (Burdge, 2001), and online homework/tutorials (Donovan, 2007), collaborative efforts at the university with other disciplines and with partners at pre-college level (Donovan et al., 2007), are other considerations that must be made.

Conclusions

This paper investigated the connection between success in mathematics and chemistry with a large popu-

lation of students at an urban commuter campus of an open-enrollment university. The connection between mathematics and chemistry success has also been investigated by other authors in varying settings and with varying sizes of populations (e.g., Strazza & Crowley, 2008). To borrow a phrase from U.S. Department of Education senior research analyst Clifford Adelman: "A story twice told should be a story to which we listen" (2006, p. xxii). As chemical educators "listen to this story" in conjunction with their program goals, they should consider the deeper and more complex issue of whether the demonstrated connection between mathematics and success in chemistry has at its base particular mathematics skills.

It is possible that the demonstrated connection is not based on the actual mathematics knowledge, but on the premise that mastering mathematics develops the same higher-order cognitive skills as those needed in science and that go beyond the simple recall of factual knowledge: "...interpretation, analysis, evaluation, reasoning, and problem solving" (ACT, Inc., 2008). If so, chemical educators face the challenge of determining whether these higher-order cognitive skills (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956) can be developed via pedagogical choices in the chemistry classroom, as an alternate to a possibly exclusionary mathematics prerequisite.

However, if success in chemistry stems from mastery of specific mathematics skills and knowledge, then those specific skills must be identified and built upon for students who will take college-level chemistry classes. [As noted above, the National Science Education Standards describe the mathematics that high school science students should be able to use and understand (NRC,1996, p. 218-219).] This raises the question of whether these skills can be integrated into the teaching of chemistry on a need-to-know basis, or if students should have well-developed mathematics skills prior to taking chemistry. The latter is the approach our university and others have taken when putting into place a mathematics prerequisite such as the one described in this paper. This approach is fairly straightforward and cost-effective, and at our institution has resulted in higher success rates in the chemistry class.

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Graphing Calculator Use in Algebra Teaching

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This study examines graphing calculator technology availability, characteristics of teachers who use it, teacher attitudes, and how use reflects changes to algebra curriculum and instructional practices. Algebra I and Algebra II teachers in 75 high school and junior high/middle schools in a diverse region of a northwestern state were surveyed. Forty of the 75 schools (53%) returned a total of 109 individual surveys. Results indicated that: (1) While 78% of teachers have some access to the technology, only 28% use it regularly. (2) Statistically significant relationships exist between use and age, years of experience, teaching assignment, and teaching level. (3) Respondents view graphical solution methods as secondary to symbolic methods. (4) Teachers are more receptive to using technology to supplement rather than expand the curriculum.

Literature Review

Current standards in mathematics education advocate technology use to promote problem-solving, reasoning, and conceptual understanding (National Council of Teachers of Mathematics [NCTM], 2000). Research supports these standards indicating that calculator use does not undermine computational ability (as cited in Dessart, DeRidder, & Ellington, 1999; Ellington, 2003, 2006; Hollar & Norwood, 1999; Smith, 1996), while it does improve problem-solving and conceptual understanding (Boers-van Oosterum, 1990; Dunham & Dick, 1994; Ellington, 2003, 2006; Hart, 1992; Rich, 1991). Studies have shown that students instructed with graphing calculators demonstrate improved understanding of functions and graphing (Boers-van Oosterum; Hollar & Norwood; as cited in Interactive Educational Systems Design, Inc., 2003; Rich), greater ability to connect multiple representations of algebraic concepts (Boers-van Oosterum; Graham & Thomas, 2000; Rich), and increased understanding of a dual approach to problem-solving, using both symbolic and graphical solution methods (Boers-van Oosterum; Harskamp, Suhre, & Van Streun, 2000; Rich). Additionally, students instructed with technology demonstrate less compartmentalization of mathematical concepts and techniques compared to those receiving more traditional instruction (Hart). Though not all studies have had positive results, relatively few have shown no benefit of calculator use (as cited in Dunham & Dick; Giamati, 1990).

When the National Council of Teachers of Mathematics (NCTM) first introduced standards for math instruction in 1989, one key component of these new standards was the assumption that appropriate calculators would be an integral part of classroom instruction and specifically graphing calculators for grades 9 – 12 (NCTM, 1989). Despite the standards and supporting research, calculator use in the classroom is still a highly debated issue among mathematics educators (Usiskin, 1999). Views range from one extreme to the other with most educators falling somewhere in between, searching for balance between calculator and pencil-and-paper techniques. Literature reveals that the calculator is most controversial when it is introduced before students master the equivalent pencil-and-paper algorithms without the technology (Ballheim, 1999). Current trends reflect this with less use of four-function calculators in elementary schools (National Center for Education Statistics, n.d.); less use of graphing calculators in Algebra I (Dion et al., 2001; Milou, 1999); and little use of symbolic manipulators at any level (Dion et al.).

Research concerning teacher attitudes and classroom practices related to technology use has identified a critical characteristic of teachers that may very well be at the center of the controversy surrounding this issue. Research has shown that teacher attitudes and practices related to graphing calculators tend to be manifestations of personal philosophies of mathematics and mathematics education, and that teachers tend to use graphing calculators as an extension of the way they would normally teach (Burrill et al., 2002; Simmt, 1997). One study used qualitative data to categorize teachers as to whether their view of mathematics was rule-based or non-rule based (Tharp, Fitzsimmons, & Brown-Ayers, 1997). They summarized their findings in the following statement,

> …Teachers who hold a more rule-based view of mathematics are more likely also to hold the view that calculators do not enhance instruction and may

> even hinder it. On the other hand, teachers with a less rule-based view of mathematics are more likely to view calculators as an integral part of mathematics and science instruction (Tharp et al., p. 558).

The findings of this study in particular clarify why there are perhaps such extreme perspectives on graphing calculator use in the classroom. As demonstrated by the study, perceptions and attitudes regarding technology are not so much aimed at the technology itself, but rather stem from teachers' personal philosophies and views of mathematics.

Considering the connection between technology use and teachers' philosophies of mathematics instruction, the current debate and trends in calculator use would indicate that the curriculum and instructional methods of pre-technology times still greatly influence mathematics instruction in today's classrooms (Simmt, 1997; Waits & Demana, 2000). One study which surveyed teachers regarding changes to algebra curriculum in light of graphing calculator technology found few changes, particularly at the Algebra I level (Milou, 1999). Coming to consensus on the technology issue will ultimately require a philosophical change for a significant number of the mathematics education community who believe allowing technology to do the computations and manipulations means allowing technology to do the mathematics.

Research Purposes

Using the discussed research themes as the bases, this study sought to determine the status of graphing calculator use among algebra teachers in a particular northwestern state, focusing on availability and usage, characteristics of teachers who use the technology, teacher attitudes concerning the role of technology in mathematics instruction, and changes currently being made to algebra curriculum and instructional practices in light of graphing calculator technology. The intent was that the insight gained from this study would illuminate areas of need regarding technology availability, teacher training, and curriculum revision that could facilitate research-based changes in the attitudes and practices of the state's mathematics education community.

Design/Procedure

Participants in the study were a convenience sampling of teachers in a regional district of a northwestern state who taught Algebra I, Algebra II, or equivalent courses. At the time of the study, the state's population was approximately 1.5 million and state averages were relatively similar to national averages with regard to median household income and education levels. The state does have a significant Hispanic population, though African-American and Asian populations are somewhat lower than national averages. The survey region was chosen using the state's high school activities association districts classification which categorizes schools by region as well as school size. Teachers of algebra courses in all public high schools in the selected region as well as junior high/middle schools from school districts represented in the selected region were asked to participate with the exception of teachers instructing algebra in alternative programs, summer programs, evening schools, and charter schools. The region surveyed was chosen due to the diversity of the schools within it, including schools ranging from some of the state's largest cities to some of the state's smaller rural communities. The breakdown of number of high schools surveyed by size is summarized in Table 1.

In January of 2006, surveys were mailed to the mathematics department chair of 75 schools with a request

Table 1
Number of High Schools Surveyed by Size

Number of Students	*N*	Percent
1280 and over	8	22
640-1297	7	19
320-639	6	16
160-319	4	11
159 and below	12	32

to distribute and collect the surveys from participating teachers with steps taken to insure anonymity. Forty of the 75 schools responded for a school response rate of 53% with a total of 109 individual surveys returned. Though the total number of teachers who potentially could have participated in the survey was not determined due to time constraints, the number is estimated to be between 150 and 300 possible participants.

Instrumentation

Participants were asked to complete a modified version of the *Use of and Attitude Towards Graphing Calculators* (UATGC) survey developed and used in a similar study (Milou, 1999). Internal content validity of the original instrument was established through review by an expert panel, revision, and pilot testing and it was noted that most items on the survey were modifications of items used in previous studies (Milou). The current study used the same survey questions with modification to the wording of items 3, 6, and 7 for clarification purposes, the omission of one question that addressed issues beyond the scope of the current study, and several additional questions asking for elaboration on respondent answers. Three questions were added to the survey asking respondents to rate their perceived level of expertise in areas related to mathematics instruction and graphing calculator technology. A separate page titled *Respondent Characteristics* developed by the authors of the current study was also included to determine general use and availability of calculators and characteristics of the respondents.

Data Analysis

Respondent Characteristics

Of the 109 survey respondents, 50% were female and 50% were male. Ages of respondents ranged from 22 to 65 with a mean age of 41.9 years and a standard deviation of 10.9 years. The number of years of mathematics teaching experience ranged from 1 to 41 years with a mean of 12.4 years and a standard deviation of 9.6. Other characteristics of respondents are summarized in Tables 2 – 7.

Table 2
Teaching Levels of Respondents

Teaching level	*N*	Percent
High school	68	62
Junior high/middle school	31	28
Both high school and junior high/middle school	8	7
No teaching level identified	2	2

Table 3
Teaching Assignment of Respondents

Teaching assignment	*N*	Percent
Algebra I only	60	55
Algebra II only	24	22
Both Algebra I and Algebra II	24	22
Other algebra-related course	2	2

Note: Some respondents selected more than one category

Table 4
Certification of Respondents

Certification level	*N*	Percent
Grades 6 – 12	82	75
Grades K – 8	8	7
Grades K – 12	15	14
No certification level identified	4	4

Table 5
Degree Majors and Minors of Respondents

Degree level	Degree major	Percent	
		Major	Minor
Bachelors			
	Mathematics	31	20
	Mathematics Education	28	0
	Science	5	14
	Physics	0	2
	Computer Science	0	3
	Elementary Education	8	0
	Other	33	31
Masters			
	Education	27	
	Mathematics	7	
	Mathematics Education	3	
	Junior High Mathematics	2	
	Educational Technology	2	
	Other	11	
Doctorate			
	Mathematics	1	

Note: Some respondents selected more than one category or did not select a category

Table 6
In-service/Training Experiences of Respondents

Training area	Percent ($N = 109$)	
	Ever	Within the last 5 years
Mathematics Content	80	63
Graphing Calculators	63	44
Technology in mathematics instruction	64	50

Table 7
Respondents' Perceived Level of Expertise

Area	*M*	*SD*
Mathematics	4.15	0.68
Using a graphing calculator	3.18	0.95
Using a graphing calculator to support algebra instruction	2.93	1.06

Note. 1 = Novice; 5 = Expert

Table 8
Graphing Calculator Availability

Degree of Availability	*N*	Percent
Classroom set of calculators	45	41
Department set of calculators	29	27
Only an overhead calculator for demonstrations	11	10
No access other than calculators provided by students	21	19
Level of availability not identified	3	3

Availability and Usage

Of the 109 survey respondents, 78% reported access to some degree of school provided graphing calculator technology. Specific availability among respondents is summarized in Table 8.

Of those teaching only in junior high/middle school settings, 71% reported at least some access to graphing calculator technology while 85% of those teaching only in high schools reported access.

Twenty-eight percent of respondents reported using calculators at least once a week. Of the 55% that taught only Algebra I, only 8% reported using calculators at least once a week. Of the 22% that taught only Algebra II, half (50%) reported using calculators weekly. Six percent of junior high/middle school teachers reported regular use while 37% of high school teachers reported regular use. Six percent of Algebra I teachers at the junior high/middle school level reported regular calculator use while 11% of Algebra I teachers at the high school level (not including those who taught both Algebra I and Algebra II) reported regular use. In addition, of the 41% who reported that they had a class set of calculators available, 49% reported using graphing calculators regularly. Of the 27% who reported access only to a department set, only 24% reported using calculators regularly.

Of those who responded that they did not use graphing calculators regularly, 29% cited availability as the reason. For others, the reasons for non-use were philosophical. Fourteen percent of respondents reporting non-use felt that students needed to be able to do the mathematics without the calculator, particularly at the Algebra I level, and expressed concerns that students become too dependent on technology if it is introduced too soon. Fourteen percent noted that use of graphing calculators was highly dependent on the topic. Time was also a factor for some (17%), particularly for new teachers and for junior high/middle school teachers whose class periods are generally shorter. Another issue noted by a small number of respondents reporting non-use (3%) was the exclusion of calculator use on state competency tests or similar tests required by their district which forced teachers to favor pencil-and-paper methods in instruction.

Teacher Characteristics Related to Use

Chi-square tests and non-directional t-tests were used to test whether a relationship existed between particular teacher characteristics and graphing calculator use. For usage analysis, only respondents indicating some form of school-provided graphing calculator technology (including only an overhead demonstration calculator) were considered. Because they did not have

Table 9
Chi Square Analysis of Relationship Between Teacher Characteristics and Calculator Use

Teacher Characteristic	χ^2	df
Gender	0.46	1
Teaching level	4.86*	1
Certification	1.05	2
Current teaching assignment	13.96**	2
Graduate degree	0.00	1
Undergraduate degree in mathematics or mathematics education	2.30	1

Note. $*p < .05$, $**p < .01$

Table 10
T-test Comparison of Teacher Characteristics Based on Calculator Use

Teacher Characteristic	Yes	No	t
	M		
Age	46.8	38.8	3.50**
Number of years teaching mathematics	16.2	10.4	2.79**

Note. $**p < .01$

the option to use technology, respondents who did not have access to school-provided technology were not considered, excluding 21 respondents from the analysis.

Statistically significant differences ($p < .05$) were found when testing the relationship between teaching assignment (Algebra I vs. Algebra II) and usage and teaching level (high school level vs. junior high/middle school level) and usage. Other characteristics were tested, but produced no statistically significant differences. Chi-Square test results are summarized in Table 9.

A non-directional t-test was performed to test the relationship between age and use by comparing the mean age of those who reported using graphing calculator technology regularly to the mean age of those who reported that they did not. The relationship between number of years teaching mathematics and use was tested in the same way. Statistically significant differences ($p < .01$) between the "yes" and "no" groups were found both for age and number of years teaching mathematics. T-test results are summarized in Table 10.

Teacher Attitudes/Curricular and Instructional Changes

To determine how teachers viewed the role of calculator technology in algebra instruction, items 6 and 7 on the UATGC survey were analyzed. Items 1 -5 were used to determine whether or not teachers supported changes to curriculum and instructional practices. Items asked respondents to indicate level of agreement with attitude statements and percentages for each category were then calculated. Each level of agreement was also assigned a numerical value to facilitate the calculation of the mean and standard deviation for each attitude statement (4 = strongly agree; 3 = agree; 2 = disagree; 1 = strongly disagree). Responses are summarized in Table 11.

Teachers were also asked to elaborate on curricular and instructional changes through open-ended follow up questions related to items 1 – 5 on the UATGC survey. Most teachers who disagreed with the introduction of graphing calculators at the Algebra I level preferred Algebra II as the introductory level (58%).

Additional topics or those receiving further development as a result of graphing calculator use included the following:

Statistics and data analysis

Conics

Table 11

Percentages, Means, and Standard Deviations for Attitudes Regarding Graphing Calculator Use in Algebra Instruction

Attitude Statement	Percentages					
	SA	A	D	SD	M	*SD*
1. Students should be introduced to graphing calculators at the Algebra I level.	17	49	20	10	2.76	0.9
2. Graphing calculators allow for algebra classes to cover additional algebraic material (topics) not covered in classes that are not using graphing calculators.	7	41	39	4	2.57	0.7
3. Graphing calculators allow for greater conceptual development of algebra topics than in classes not using graphing calculators.	13	45	29	5	2.72	0.8
4. Graphing calculators allow for omission or de-emphasis of certain algebraic topics.	8	21	51	9	2.32	0.8
5. Students should be permitted to use graphing calculators during ALL tests.	3	17	44	30	1.92	0.8
6. When graphing calculators are used in instruction, students should first solve symbolically and verify graphically.	25	57	10	0	3.16	0.6
7. When graphing calculators are used in instruction, symbolic methods are preferred to graphical methods.	6	44	27	0	2.74	0.6

Note. SA = Strongly Agree = 4; A = Agree = 3; D = Disagree = 2; SD = Strongly Disagree = 1

Matrices
Systems of equations and inequalities
Financial applications
Complex graphing
Graph families
Connections between graphical and symbolic representations
Functions

Statistics and data analysis was mentioned most frequently as an addition to curriculum (15%) while graphing was mentioned most frequently as a topic developed more fully with graphing calculator use (28%).

Omitted topics or those receiving de-emphasis in light of graphing calculator technology included the following:

Point plotting
Tedious graphing
Solving systems of equations algebraically
Solving quadratics algebraically
Simplifying radicals
Rationalizing denominators

In response to testing practices, there seemed to be some agreement that tests related to graphing should not allow graphing calculator use (18%) and many responses implied that graphing calculators should not be allowed for other topics unless student mastery of the topic without the calculator had been previously demonstrated on another test (17%).

Discussion

Limited Use in Spite of Availability.

The data suggest that usage of graphing calculators in this particular region is still fairly limited with only 28% of respondents indicating regular use; however, some respondents indicated that usage was largely tied to the topic being studied. Calculators were used daily for some topics and not at all for others, so the definition of regular use as "at least once a week" may have been troublesome for some respondents.

The data also suggest that some form of school-provided graphing calculator technology is available to most teachers (78%), however limited it may be. The fact that the percentage of teachers using graphing calculator technology was more than double for teachers

with classroom sets as opposed to department sets suggests that degree of access does make a difference. The general sense from comments on the surveys was that the extra effort of tracking down a calculator set greatly discourages calculator use for a busy teacher.

Teaching Assignment and Level Related to Use

Though not surprising, the data suggest a relationship between use and teaching assignment (Algebra I vs. Algebra II) and use and teaching level (high school vs. junior high/middle school). This was evidenced by the statistically significant difference between usage in Algebra I and Algebra II with only 8% of those teaching only Algebra I reporting regular usage while 50% of those teaching only Algebra II reporting regular usage. These findings are consistent with national trends among mathematics educators which favor use of graphing calculators in higher level mathematics (Dion et al., 2001). Given the difference in usage for teaching assignment, it would make sense that there would also be a statistically significant difference between usage at the junior high/middle school level and usage at the high school level since all junior high/middle school teachers in the study were Algebra I teachers.

Age and Experience Related to Use

Somewhat surprising though, was the indication that usage is higher among older teachers with more experience. One might expect that newer teachers growing up and being prepared as teachers in a technological society would be more likely to use technology more readily in their instruction. Possible explanations for these findings might be that typically older, more experienced teachers are assigned the advanced courses to teach. More experienced teachers may also be more comfortable with content and instructional practices and thus more likely to experiment and explore new approaches.

Graphical Methods Secondary to Symbolic Methods

The fact that 82% of respondents expressed agreement with attitude statement 6 and 50% agreed with statement 7 suggests that in general, respondents view graphical solution methods as secondary to symbolic methods in algebra instruction. However, there was more disagreement with item 7 (27%) which directly stated that symbolic methods were preferred as opposed to item 6 which places graphical methods in a supportive role behind symbolic methods. The responses to these two attitude statements may seem somewhat contradictory considering that both address the role of graphical and symbolic approaches, but perhaps the slight contradiction just highlights the struggle teachers are having with balancing long-standing methods with technological capabilities. It would seem teachers are receptive to using both types of solution methods in instruction, but have not yet fully embraced graphical methods as a valid replacement for some symbolic methods.

Technology Supplements Rather than Expands the Curriculum

Based on responses to items 1 – 5 (see Table 11) and responses to open-ended components associated with these items, teachers are slowly making changes to curriculum and instruction in light of technology, though the changes are subtle. There was more agreement with item 3 (58%) than with item 2 (48%) which indicates that teachers are more receptive to using technology to supplement development of current topics than to using technology to expand the curriculum. Statistics and data analysis appeared to be the most common addition to algebra curriculum as a direct result of technology availability, but in general, respondents appeared to feel technology is most useful for further developing topics already included in the curriculum. There was the least agreement with item 4 (29%) concerning omitting topics which may partially explain why few topics are being added to curriculum. Some topics of traditional curriculum must be omitted to make way for additional topics.

Curricular Changes Consistent with NCTM Recommendations

Responses to items 1 – 5 suggest that, at least to some extent, NCTM recommendations for changes in content emphasis as they apply to technology use are influencing the curriculum. Matrices, using technology to aid in conceptual development, and the emphasis on functions and connections between symbolic and graphical representations were all listed by respondents as areas receiving increased emphasis and further development. In addition, graphing by point plotting, simplification of radicals, and the use of factoring to solve quadratic equations were listed as areas of decreased emphasis. These changes are all consistent with NCTM recommendations (NCTM, 1989) and represent small steps toward re-shaping mathematics curriculum in light of our technological capabilities.

Findings Consistent with Milou Study

Responses to the *Use of and Attitude Towards Graphing Calculators* were fairly consistent with the findings of the 1999 Milou study from which the *Use of and Attitude Towards Graphing Calculators* survey

of the current study was adapted (Milou). While the Milou study allowed for a neutral response and used different statistical analysis techniques which prevent a direct comparison of results, the study did report higher agreement among respondents that graphing calculators should be introduced at the Algebra I level, that graphing calculators allow for additional topics and more in-depth study of current topics, and that calculators should be used in a supportive role behind algebraic methods (Milou). These attitude statements (items 1, 2, 3, and 6) were among those with greater agreement in the current study as well.

The Milou study (1999) asked respondents to elaborate on additional topics being included in algebra curriculum as a result of graphing calculator technology as well as those topics being omitted or receiving decreased attention. Both studies highlighted statistics and data analysis as one of the most frequently mentioned topics added to curriculum in light of technology (Milou). Other topics mentioned in the Milou study included matrices, complex graphing, functions, and financial applications, all of which were mentioned by respondents in the current study as well. The three topics mentioned most as being omitted or de-emphasized were factoring, student produced graphing, and rational expressions (Milou). Again, these responses were fairly consistent with responses in the current study.

A comparison of the results of the Milou study (1999) and the current study would seem to suggest that in the span of nearly ten years between the two studies, algebra curriculum and teacher attitudes have experienced very little significant change in light of technology.

Limitations of the Study

While this study provides some insight into the status of graphing calculator use in algebra classrooms today, it should be noted that there are some issues which may limit the ability to generalize results. Though demographic information has been provided to facilitate comparisons to other regions, the study was limited to a selected region of a single state and results may not be representative of all states. State and school district mathematics curricula and policies may influence calculator use. Additionally, for ease of distribution, surveys were distributed by mail through department chairs which likely contributed to the 53% return rate and the inability to calculate an individual response rate. Entire schools may have been eliminated from the study at the discretion of a single department chair. Also, the self-reporting nature of this method of study also creates some degree of bias which must be considered. Teachers' perceptions of their use of technology and assessment of their personal attitudes toward technology may not be entirely consistent with their actual practices.

Conclusions

While research suggests that technology may be a critical component for conceptual development and problem-solving as well as for exploring patterns and relationships in mathematics, this study reveals that teachers are still unsure of how to reconcile technology's capabilities with mathematics curriculum as they know it. Graphing calculators are fairly readily finding their way into Algebra II instruction as students move past learning many of the basic algorithms of algebra, but there still appears to be hesitancy on the part of Algebra I teachers to make significant curricular changes. Many still cling to the idea that one must be able to do the mathematics by hand in order to understand and use it. While that may be true in some cases, is it always true? Is our current focus the most effective use of limited instructional time? The sense gained from this study is that teachers are generally receptive to using technology in mathematics instruction but are unsure about the details. Some lack the technology altogether while others just lack the skills to use it effectively. Some are looking for specifics about how and when to use technology in curriculum. All are looking for assurances that the changes they make will improve student achievement and understanding.

While providing some insight into current use of technology in the particular region studied, there are many issues concerning technology use not addressed by this study.

Probably of greatest importance, further study is needed to determine how technology affects student achievement. What type of technology use is most beneficial for students? At what point is the introduction of graphing calculator technology the most effective? What pencil-and-paper techniques must be developed first in order for graphing calculator technology to be used appropriately? Does use of graphing calculator technology at the Algebra I level weaken students' ability to apply, interpret, and use graphs? Does doing an algorithm by hand prior to technology use truly aid in understanding of the results? What pencil-and-paper algorithms can be omitted without compromising student understanding?

Also of importance, more in-depth study of what occurs in classrooms as it relates to technology use would be insightful. Are teachers' perceptions of their use of technology and assessment of their attitudes towards technology consistent with their actual practices? How is the graphing calculator being used in daily instruction and what qualities of the way it is used make it most effective?

Finally, comparisons of the findings of this study with other similar studies would be helpful. Are the findings in this study consistent with technology use in other states? Is technology use at the high school level consistent with technology use at the college and university level? What is the status of technology use related to computer algebra systems?

Many of the questions raised in connection with the current study would likely require the use of interview and observation to fill in the details. Particularly for teachers at introductory algebra levels, research must address the concerns associated with whether technology use early on produces student weaknesses that cause problems in subsequent courses.

With studies like this one and others similar to it as a starting point to direct and motivate further studies related to this very important issue in mathematics instruction, those details can be filled in. Each detail serves to move us closer to a mathematics curriculum that is relevant, useful, and required in our ever-changing society, a curriculum in which technology is sure to play a critical role.

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Model-Based Inquiry and School Science: Creating Connections

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Much has been made in recent years of inquiry approaches to science education and the promise of such instruction to alleviate some of the ills of science education, yet in some ways this construct is still unclear to many in the field. In this paper we explore one view of inquiry in science that is based on the development, use, assessment, and revision of models and related explanations. Because modeling plays a central role in scientific inquiry it should be a prominent feature of students' science education. We present a framework based on this view that can serve as a guide to curriculum development and instructional decision-making with the goal of creating classroom environments that mirror important aspects of scientific practice. Specifically, the framework allows us to emphasize that scientists: engage in inquiry other than controlled experiments, use existing models in their inquiries, engage in inquiry that leads to revised models, use models to construct explanations, use models to unify their understanding, and engage in argumentation. Here, we discuss how these practices can be incorporated into science classrooms and illustrate that discussion with examples from our research classrooms.

In the United States and many other countries there is grave concern about the state of science education. This concern stems from two related issues: first, that many schoolchildren are leaving secondary school without an understanding of even the most fundamental ideas in science and second, that many capable students are not choosing to continue studying science at the college level. When science instruction is incomprehensible and uninspiring it fails the most basic mission of science education. Much has been made in recent years of inquiry approaches to science education and the promise of such instruction to alleviate some of the ills of science education. The current focus on this issue began in the 1990s when scientists and science educators undertook a lengthy process that resulted in the publication of the *National Science Education Standards* (National Research Council [NRC], 1996). Broad in scope, the *NSES* presented an ambitious agenda for far-reaching reform that identified the primacy of inquiry to science and to an education in science. "They [the *NSES*] emphasize a new way of teaching and learning about science that reflects how science itself is done, emphasizing inquiry as a way of achieving knowledge and understanding about the world" (NRC, p. ix).

This vision is still unrealized in many science classrooms (Crawford, 2007). We suggest that perhaps one reason for this is a lingering lack of clarity about what exactly inquiry is in the context of science education and how it contrasts to other approaches. In particular, there is often a conflation of hands-on science with inquiry and while true classroom based inquiry is almost always hands-on, the reverse is not true. We claim that the key in deciding if something is consistent with inquiry is to determine the fidelity between the intellectual work being asked of students and that which might occur in the work of science. Thus, our working definition of inquiry in science education is focused on the process of developing explanations about the natural world through participation in the complex activities of scientific practice. That is, inquiry is the act of systematically investigating and exploring aspects of the natural world in order to develop coherent explanations for how those features of the world work. In this paper we explore this view of inquiry and a framework that has developed from it. Our view and the framework are based on a number of years of classroom-based research and theoretical exploration of the issues facing science educators. The purpose of this paper is to clearly and explicitly delineate ways in which our perspective on inquiry can lead to classroom environments that go beyond mere hands-on work to those which

promote reasoning that is consistent with what scientists actually do.

Situating science teaching in the context of inquiry is not new. Early in the twentieth century, Dewey (1910) called for science to be taught through inquiry experiences and chastised status quo teaching for presenting science as "...so much ready-made knowledge, so much subject-matter of fact and law" (p. 124). Five decades later, one of the 20th century's leading science educators, Schwab (1958) argued that science teaching should focus on how scientific knowledge is created and justified rather than upon a "rhetoric of conclusions"— his phrase for an emphasis on knowledge, independent of an understanding of how that knowledge is produced. Schwab urged that science be taught by inquiry and made it clear that inquiry involves more than familiarity with the formulaic "scientific method" found in K-12 instruction (typified by the steps: problem, hypothesis, experiment, results, conclusion). For Schwab and others, this version of inquiry—beginning as it did with problem and ending with conclusions—was inconsistent with actual scientific practice (Rudolph, 2005). However, despite the efforts of many science educators to incorporate a realistic vision of scientific inquiry into science instruction, little has changed (Crawford, 2007; Windschitl, Thompson, & Braaten, 2008).

Recently though, educators have once again returned to considering what view of inquiry would be appropriate as an underpinning for developing curricula and instruction for K-12 science classrooms (Duschl, Schweingruber, & Shouse, 2007). In some cases the attention to inquiry has been sweeping, lacking in specificity in terms of how classroom practices relate to scientific inquiry writ large, and therefore limited in utility. However, many scholars have come to recognize that scientific inquiry differs among disciplines and that discipline-specific conceptions circumscribe the questions scientists ask as well as the approaches they take when pursuing answers to those questions (Rudolph, 2005). This approach too, has a drawback in that paying too much attention to the specificity of individual scientific practices could result in a view that is so detailed that it also lacks utility.

We argue that a middle ground is essential if inquiry science instruction is to have any hope of being incorporated into classroom practices and more importantly if it is to lead to scientifically literate students who are inspired rather than overwhelmed by science as an intellectual activity. Thus, the framework presented here is in service of this goal: scientific literacy defined as an understanding of the content of science coupled with an understanding of how that knowledge was generated and justified. This has led us to look for commonalities across disciplines, commonalities of purpose that can accommodate uniqueness in approach.

We have found that model-based reasoning is a cornerstone of every discipline to some degree (Derry, 1999; Frigg & Hartmann, 2006; Giere, 1988; see also Gilbert & Boulter, 2000). That is, all scientific disciplines are guided in their inquires by models[1] that scientists use to construct explanations for data and to further explore nature. The development, use, assessment, and revision of models and related explanations play a central role in scientific inquiry and should be a prominent feature of students' science education.

In this paper we present a framework that reflects a model-based inquiry view of science (Figure 1). A benefit of this framework is that it is more realistic than the textbook "scientific method," because it acknowledges the discipline-specificity of inquiry, and yet because the Practice Framework captures aspects of inquiry common to all disciplines it is general enough to be of value in planning curricula and instruction for any school science area. We recognize that many others have called for modeling and model-based inquiry to be incorporated into science education (most recently see Windschitl et al., 2008). However, the Practice Framework is the only curricular framework that we are aware of that shows the relationships between and among models, explanations, phenomena that make up discipline-specific practice.

At the heart of the Practice Framework is the recognition that models are a cornerstone of every science discipline. The significance of models is that they allow scientists to construct explanations for data and to predict patterns in data. The model itself is a set of "set of hypothesized relationships among objects, processes, and events" (Windschitl & Thompson, 2006, p. 796). That is, the model brings together the theoretical objects and the processes they undergo and thus serves as a mechanism that can be used to explain why something in the natural world works the way it does. Typically models are clustered together to form scientific theories (Giere, 1988). For example, evolutionary theory is comprised of a set of models that includes natural selection, genetic drift and various models of speciation that can be used to construct explanations for changes in populations over varying pe-

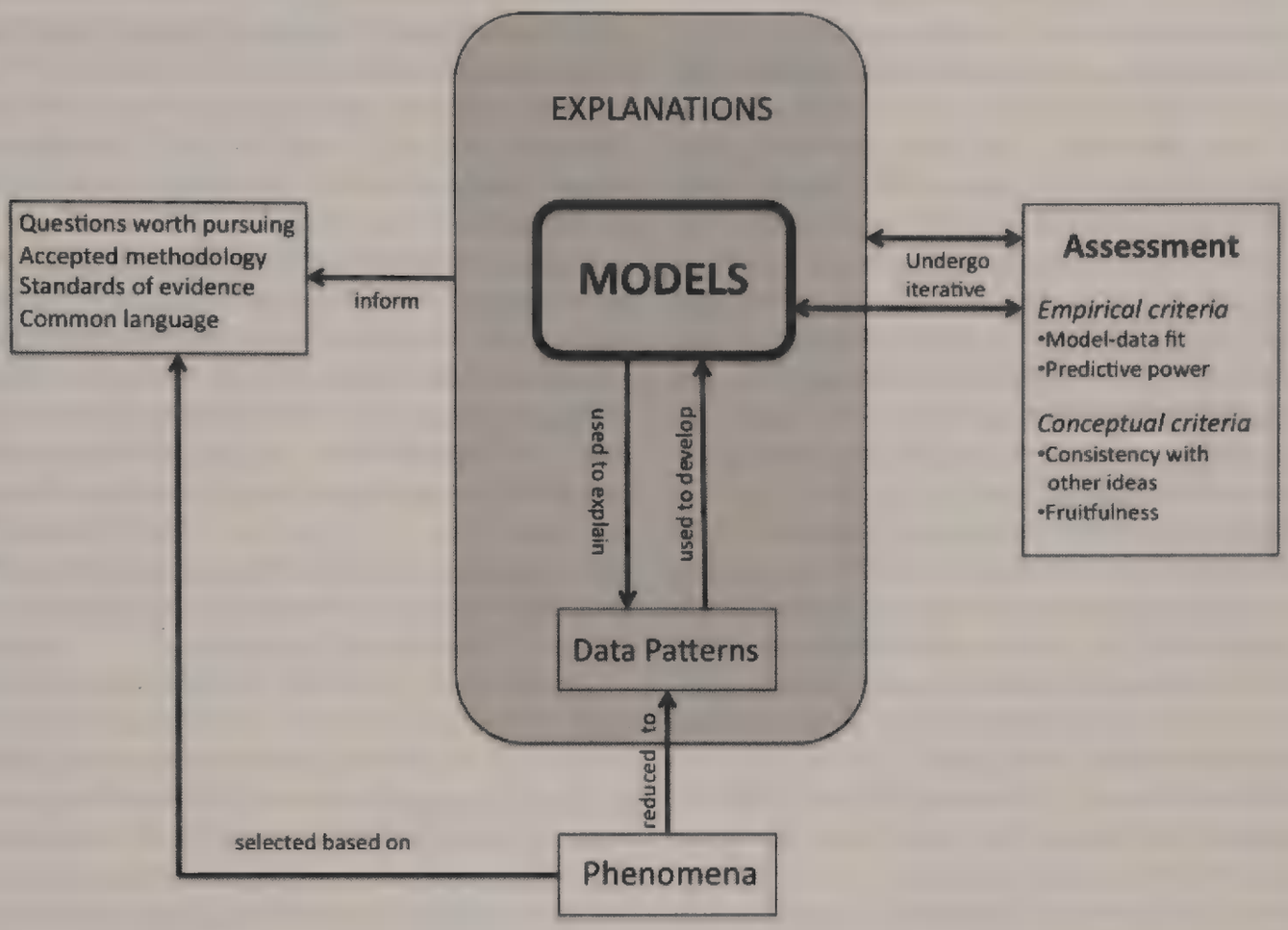

Figure 1. Models are placed at the center of this depiction of discipline-specific practice and highlighted as central with a bold line. The words models and data-patterns are nested within the larger construct of explanation in order to illustrate that explanations are distinct from models, but are structures that bring models to bear on particular data patterns that have been abstracted from phenomena. The right side of the diagram shows that both models and explanations undergo assessment based on conceptual and/or empirical criteria. That is, sometimes the model may be critiqued in isolation, but more often it is an explanation arising from the model that is evaluated leading to an assessment of some aspect of the underlying model (or a re-evaluation of what was considered the relevant data pattern). The left side of the framework is meant to convey that key models and accepted explanations within disciplines are important inputs into the norms of the practice and those norms then are important filters through which practitioners view the world and the phenomena that may need exploration.

riods of time. Because models are so important in science, students should be engaged in reasoning with them and about them.

Towards a Realistic View of Scientific Inquiry

To be considered scientifically literate, students should understand that the methods by which disciplines generate and justify knowledge are diverse and are deployed within practices. Disciplinary practices are comprised of communities of inquirers who are organized around discipline-specific models, language, questions, and reasoning patterns (Kitcher, 1993). The Practice Framework reflects key elements of scientific practice that are useful when designing curricula, making instructional decisions, and assessing students. Of particular value is the emphasis on the role of models in: asking questions, recognizing data patterns, constructing explanations for data, and in providing criteria for judging knowledge claims. In addition, the Practice Framework emphasizes that scientific understanding is embedded within, and inseparable from, the processes by which explanations and models are created, used, assessed and revised.

The Practice Framework represents the products of inquiry (e.g., explanations and models) as embedded within the processes by which they are created and therefore downplays the content-process dichotomy

that is present in some recommendations for science education (see for example *the Science Content Standards for California Public Schools*, California Department of Education, 2003). That is, the Practice Framework places the specific content knowledge in a particular discipline at the center of the process of inquiring into that area. The integrated nature of the Practice Framework makes it useful when designing classrooms where students function as scientists. During the past decade, we have used the Practice Framework to design curricula in genetics, evolutionary biology, Earth-Moon-Sun astronomy, and kinetic molecular theory. In addition, middle and high school teachers with whom we have collaborated have used the Practice Framework to guide instructional decisions (Cartier, Passmore, Stewart, & Willauer, 2005). Focusing on data patterns and models helps the teachers organize tasks and structure interactions as students make sense of complex phenomena and judge competing models and explanations. As a result, students develop understanding as measured by their ability to make sense of novel phenomena (Stewart, Cartier, & Passmore, 2005; Stewart, Passmore, Cartier, Donovan, & Rudolph, 2005).

We have organized this article around six aspects of scientific practice that are brought to life by using the Practice Framework. Although a tool as complex as the Practice Framework has many ideas embedded within it, we've chosen to focus on these six aspects of practice because they are currently underemphasized in many science classrooms. These aspects of practice are also often absent from activities that might be characterized as only hands-on and thus can be used to further explicate the distinction between engaging, hands-on science instruction and approaches that could be characterized as inquiry as well. Several key points are worth making here and will be illustrated with appropriate examples from our research classrooms. Specifically, the framework allows us to emphasize that scientists:

- engage in inquiry other than controlled experiments,
- use existing models in their inquiries,
- engage in inquiry that leads to revised models,
- use models to construct explanations,
- use models to "unify" their understanding, and
- engage in argumentation.

Complete descriptions of the instructional units and results of studies on student understanding can be found in Barton (2001), Cartier and Stewart (2000), Johnson and Stewart (2002), Passmore and Stewart (2002), and Wynne, Stewart and Passmore (2001)[2].

Exploration of Aspects of Scientific Practice

Scientists engage in inquiry other than controlled experiments. While it is true that many scientific disciplines conduct controlled experiments as part of their investigations into the natural world, it is simply not the case that this practice is common across all disciplines or that it should be held up as the exemplar of all science. The ubiquity of experimental science is implied and codified in the textbook "scientific method". When developing model-based inquiry instruction we do include aspects of the "scientific method," particularly hypothesis testing and experimentation. However, we embed them in a conception of inquiry that recognizes that scientists use diverse inquiry methods in order to generate and interpret data as a basis for developing explanations for phenomena.

The textbook view of inquiry, "the scientific method," emphasizes the role of hypotheses but in doing so has shortcomings. For example, hypothesis is followed by experimentation, often narrowly conceived of as controlled experiments. But if there were a universal linear set of steps that scientists follow, hypothesis would be followed by a more general activity, investigation. Why? Because not all scientists conduct controlled experiments. Ethologists (biologists who study animal behavior) generate hypotheses but may not always be able to test them with controlled experiments. It would be impossible to conduct a controlled experiment to choose between the hypotheses that different species of primates display similar predator warning behaviors because of 1) the environment they live in or 2) a common evolutionary history. To choose, ethologists employ a comparative approach in which they observe many species (without experimental manipulation), compare the DNA of those species and examine the fossil record for evidence about the species' history. Comparative methods are common in sciences, such as evolutionary biology and geology, where historical evidence is significant.

Our astronomy curriculum can be used to illustrate classroom inquiry that is not experimental in nature. In classrooms using this curriculum students investigate near-Earth astronomical phenomena such as phases of the moon and eclipses (Barton, 2001). Although students do not conduct controlled experiments, they do test their ideas in systematic ways. They first explore the phenomena and look for patterns. In the case of moon phases this is accomplished through detailed ob-

servations of the moon over several weeks. Once they find a pattern they attempt to explain that pattern by developing a model for how the Earth, moon, and sun must interact to create what we see on Earth. They may use diagrams, globes, balls, and light sources to create their model. They develop an idea and then "see" if they can recreate the phenomenon. This is clearly an investigation where they are moving between conceptual and observational modes, but these actions cannot be called experiments in the traditional sense. Once they have figured out one or more ideas (models) for Earth, moon, sun interactions that can be used to explain the phenomenon, they test those ideas by developing explanations and creating arguments in support of their models.

It is important that we be clear here. We are not saying that controlled experiments are not worthy of emphasis or that they do not make up much of science. Instead, the point here is that they are not all that scientists do and, depending on the discipline, may not play a significant role. Students who are scientifically literate should be able to see that there are a variety of legitimate modes of inquiry within science.

Scientists use existing models in their inquiries. Scientific understanding results when scientists (and students) use models to explain phenomena. For example, simple dominance is a genetic model that is one member of a family of models. It includes objects (i.e., alleles and genes), processes that those objects participate in (segregation and independent assortment), is related to other biological models (e.g., of gene expression and chromosome behavior) and allows scientists and students to explain some pedigree data and to predict the results of crosses.

Unfortunately, the textbook scientific method often fails to acknowledge that hypotheses are embedded in disciplinary traditions that include models and the discipline-specific reasoning patterns that scientists use to pose and pursue problems. Too often the beginning of an inquiry in school science is presented without any background information. In some cases students are asked to generate questions about some observations without any context. If instruction stresses only the textbook scientific method, students may not understand that scientific inquiry is iterative and builds on the results of past inquiries in which scientists used models to generate new knowledge that then is used in future inquiries. To engage in inquiry is to be a member of a community of practitioners who understands the nature of the problems worth solving and who is able to employ the discipline's reasoning patterns to seek solutions to those problems. School science should better reflect the model-based nature of inquiry.

In the genetics curriculum developed by our team, students are introduced to this process in a meaningful way. They begin with a conceptual exploration of meiosis and then they learn about the work of Mendel. As part of this instruction these two models are explicitly linked when students are asked to make sense of Mendel's idea that each individual has two "factors" controlling each trait. As they investigate more genetic phenomena they are able to recognize instances in which Mendel's simple dominance model fails to account for the data and they then revise that model in light of the anomalous data. For example, Mendel's model can only account for traits with two distinct variations and thus traits with more than two variations become anomalous with respect to Mendel's model. Without knowledge of the simple dominance model the students would not be able to recognize that there was something in need of explanation in a particular data set. Moreover, the previous two models (meiosis and simple dominance) constrain the model revision process by circumscribing the problem space in productive ways. For example, students might initially propose a model that postulates 3 alleles per individual for a particular trait. They quickly realize, however, that such a model would be inconsistent with meiosis and therefore the range of ideas they explore is influenced by the scientific models they are working with at the outset of a new exploration (Wynne et al., 2001).

Too often in science classrooms students are presented with key ideas as a set of disassociated facts (Roth et al., 2006). Many times they do not naturally make connections between ideas and they are very seldom asked to do so. Engaging students in model-based inquiry presents an authentic context that requires them to make connections and use one set of ideas to lead them in their investigation of new ideas. This is a much more accurate reflection of what scientists do and has the potential to add coherence to the science curriculum.

Scientists engage in inquiry to develop and revise models. There is inquiry other than testing hypotheses by experimentation or by other equally scientific, but non-experimental methods. Such inquiry occurs when there is no model that accounts for a range of observed phenomena or when models are found to be internally inconsistent, inconsistent with new data, or with other accepted knowledge. When these inconsistencies

occur, the inquiries of some scientists turn from using a model to solve empirical problems to conceptual inquiry aimed at remedying the noted inconsistencies. Inquiries of this kind may require models be constructed anew, abandoned, or more often revised. Take for example the work done by Waston, Crick, and others in developing a model of the DNA molecule. Much was known, from empirical studies, about the attributes such a molecule must have, but little was known about the structure and thus the utility of this information was limited. The breakthrough came when these scientists synthesized information from a number of sources and postulated a structure. Once the model (the double helix structure) was proposed, more empirical work could be undertaken to test it. Such conceptual inquiries—in which scientists examine the coherence of their discipline's accepted knowledge—are significant to science yet, they are rarely represented in science classes. If students view inquiry as only empirical manipulation, they may not value the contributions of conceptual inquiry to science.

We will use the astronomy curriculum to illustrate this point. One of the phenomena that students explore in this course is eclipses. They are presented with data on the frequency of eclipses and are asked to use their understanding of the Earth, moon, sun system to explain the pattern they see in the data. Specifically, they need to explain that eclipses occur in pairs of one lunar and one solar eclipse approximately every six months. Up to this point, the students have already developed a model in which the moon orbits the Earth one time approximately every 28 days and that the direction of the orbit is the same direction as the rotation of the Earth. Most students, however, have not described the planar orientation of this orbit at all and it is this issue that they are forced to confront because of the eclipse data. Many of them quickly realize that the simplest way to avoid having an eclipse during a new or full moon phase is to move the moon out of the Earth-sun orbital plane. At this point their inquiries become largely of the conceptual nature noted above. That is, the students must postulate a mechanism that would allow the moon to be out of the Earth-sun plane most of the time, but cross it at key points. In undertaking this inquiry they are reminded that their ideas must fit with the general principles of physics and that any revisions they make to their model must not jeopardize their ability to explain the data that they had explained previously (moon phases, for example).

Science curricula should provide students with opportunities to experience conceptual inquiry as they develop, use and revise models in response to anomalous data or to contradictions with other accepted models, and to assess those revised models for empirical and conceptual consistency. Conceptual inquiry, while common in science, is rarely introduced in traditional science classrooms.

Scientists use models to construct explanations. It is through the act of constructing explanations that scientists come to understand the natural world. This intimate connection of explanation to understanding should be of interest to science teachers. If students develop and justify explanations then they have participated in science and then have the opportunity to develop metaknowledge of this practice. It is that metaknowledge of how knowledge is generated and justified in science, coupled with the particulars of the major scientific models, that is the hallmark of science literacy.

Scientists pose and seek answers to questions about unique events (why was there a fish kill in Black Earth Creek in the late summer of 2001?) or for patterns in events (why do many members of the Lu family have difficulty digesting dairy products?). Such questions result in answers that take the form of explanations in which a model, or models, is joined with empirical observations (data). In the case of the Lu family this process might involve creating an explanation, using a genetic model such as simple dominance, to explain why some family members have an allergic reaction to dairy products. Alternatively, an explanation might be developed, using evolutionary models, to explain the absence of an enzyme for digesting dairy products in certain populations based on ideas about selective advantage.

Our natural selection curriculum illustrates this point particularly well. In this unit students first explore the natural selection model and its underlying components (such as variation, selective advantage, superfecundity and so on). Once they have a clear understanding of the model they employ it to explain natural phenomena (see Passmore & Stewart, 2002 for a complete description of this curriculum). They are asked to create Darwinian histories of extant organisms by drawing on the tenets of natural selection and information about the organism and its habitat. For example, in one case study they are presented with data related to monarch and viceroy life histories and asked to explain the similarity in color between the two distantly related butterfly species. In crafting their explanations they must

weave together information about the butterflies with their knowledge of the natural selection model. That is, they know that natural selection relies on heritable variation and that in order for a particular trait to become more common in the population it must confer some kind of selective advantage on individuals with that trait. This leads them to consider what evidence they have in their information packets about variation and the environment so that they can make specific claims about the organisms in question and the selective advantage of particular trait variations.

Because model-based explanations are central to science they should occupy a prominent position in school science. Students should be given opportunities to see that the scientific ideas they learn about (the models) are useful in developing explanations for patterns in the natural world. Requiring students to use their knowledge to construct explanations for natural phenomena is quite different from asking them to simply repeat the ideas back on a test. The former is much more relevant to the intellectual enterprise of science than the latter and more likely to lead to understanding of both the content and process of science.

Scientists use models to unify understanding. Scientific disciplines are highly unified because models serve to bring together phenomena and because models are organized into "families" (Giere, 1988). For example, if a researcher were to examine human and fruit fly pedigrees she might observe similar patterns yet, because humans and fruit flies differ in appearance, it may not be obvious to explain the similar patterns with a single model. This is what is possible given Mendel's model of simple dominance (and other genetic models); diverse phenomena are brought together within one explanatory structure.

In addition, a discipline gains coherence because its models fall into model families. For example, students see when looking at pedigrees in the genetics course that there are obvious patterns found in some pedigrees and not others. However, as they engage in the model revision process they see that the models used to explain these diverse pedigree patterns share a 'family resemblance' in that there are some number of alleles in the population of organisms from which the pedigree is constructed, some subset of those alleles occur in each individual, there are certain allele combinations that occur in individuals, and alleles interact with one another in prescribed ways. In this example, classical genetics is 'unified' by bringing seemingly diverse causal models (e.g., simple dominance and multiple alleles) under a single family structure. As a result, students see that genetics has a conceptual and explanatory coherence, rather than being a grab bag of unrelated facts to be committed to memory.

Scientists engage in argumentation. In science and in science classrooms, argumentation is the public face of inquiring, modeling, and explaining. Argumentation is the process by which scientists assess the adequacy of their explanations for data patterns and of the models that they have used to develop those explanations.

Argumentation occurs throughout an inquiry and although it is public in nature it does not require large audiences—it can occur between two individuals throughout an inquiry. When focusing on explanation as a part of argumentation one must be concerned with the consistency of the explanation. Specifically, one must make sure that it does not violate the assumptions of the model that is used in its construction and that it accounts for the phenomena/data at hand. In the model-based inquiry classrooms we have created, argumentation is valued. Across these classrooms one could observe students engaged in a range of the activities including:

- using models to pose questions and to generate data to address those questions
- developing an appropriate language for conversing about models and explanations
- revising causal models in light of anomalous data
- developing explanations that link causal models and data
- assessing models and explanations

The model-based inquiry context allows for multiple entry points into the practice of argumentation. It is important to note, however, that effective argumentation does not come easily to middle school or high school students. They need to be introduced to norms of interactions that allow communities to disagree profitably and they need to develop discipline-specific norms of argumentation. A classroom where argumentation is taken seriously involves more than students making presentations to classmates with only limited interaction. Teachers who are committed to having classrooms function as scientific communities realize that this is a long-term commitment, one that requires careful planning and orchestration. Making scientific arguments involves a deft coordination of data and models resulting in an explanation. Similarly, students who are being persuaded have a significant role—they have to attend to the argument, be aware of the standards for assessing explanations, and be inclined to use

those standards in their interactions with others. (Driver, Newton, & Osborne, 2000)

Summary

We began this article by noting the growing consensus about the value of engaging students in inquiry. We agree that inquiry is important because, in part, we define understanding as the ability to inquire. Further, we have argued that inquiry is a process of developing explanations about the natural world through participation in the complex activities of scientific practice. Thus, scientific knowledge cannot be teased apart from its generation and use, and to engage the activities of scientific practice is key to developing and demonstrating understanding. The complex and elusive nature of scientific understanding creates a significant challenge for educators struggling to identify learning outcomes for students and to develop ways to assess student understanding. For students, understanding science is the ability to function within a particular practice and requires that they couple their knowledge of causal models and the justification for their acceptance with the ability to use that knowledge to make sense of novel phenomena.

Given its consistency with the activities of scientific communities, our Practice Framework is a valuable tool for curriculum designers and teachers and may have implications for science education reform efforts. In the current educational landscape of high stakes testing and accountability, achieving an educational experience for students whereby they begin to see the logic and conceptual consistency of science is crucial. The testing climate has the potential to further fracture the coherence of science education by focusing too much on the acquisition of disparate information, but in fact, a focus on model-based inquiry can help develop coherence in the curriculum and help students develop deeper understanding. Recognizing that understanding in science develops in classrooms inspired by realistic scientific practices may help the science education community create a clear and sophisticated vision of scientific inquiry that can guide curriculum and professional development (Windschitl et al., 2008). The Practice Framework codifies some of the key relationships inherent in such a view. Students deserve an experience in school science that is comprehensible, coherent, and intellectually inspiring and by creating classrooms that mirror important aspects of scientific practice all three of these purposes can be achieved.

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[1] There are many definitions of models in the science education and science studies literature. For our purposes here we use the following definition: models are sets of ideas that consist of objects and the processes that the objects undergo, or as Windschitl and Thompson (2006) put it, a model as a "set of hypothesized relationships among objects, processes, and events" (p. 796). Models are used to explain and predict patterns in data (e.g., Gregor Mendel's simple dominance model and Charles Darwin's natural selection model are examples of central models in biology).

[2] Instructional materials for the EMS unit and for one in evolutionary biology are available at the MUSE website http://www.wcer.wisc.edu/ncisla/muse/

Science Conference Presenters' Images of Inquiry

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Inquiry-focused professional development and conceptions of inquiry held by eight professional development leaders were investigated within the context of a state science teacher conference. The prominent session format involved session leaders modeling classroom experiences. In all sessions, classroom inquiry was portrayed as a teacher-guided activity with the primary goal being to increase motivation for engaging students in classroom inquiry. The leaders' conceptualized inquiry primarily as a teaching approach with various goals, characteristics, and potential barriers. The findings of this study provide evidence of how inquiry, a prominent feature of science education reform, was portrayed in sessions at a conference sponsored by a state affiliate of the National Science Teachers Association and thought about by persons who led these sessions. The findings have implications for teacher learning from conference-based professional development and its potential influence on science teacher thinking and practice.

Science educators advocate classroom experiences that feature inquiry as a means to help students come to understand science as a process of investigating and thinking in addition to a body of facts (National Research Council [NRC], 2000; Schwab, 1962). Unfortunately, inquiry as described in reform-minded documents is not always realized in science classrooms (Abrams, Southerland, & Evans, 2007). One reason for this may be linked to how inquiry is portrayed in the professional development experiences of science teachers. An important professional development experience for many science teachers is participation in state science teacher conferences.

Conferences sponsored by the National Science Teachers Association (NSTA) and its state affiliates have been promoted as opportunities for science teacher professional development for decades, yet the influence of these conferences on teacher learning remains virtually unreported in the science teacher professional development literature (see Hewson, 2007). Although it is clear that NSTA and its state affiliates exert a powerful influence on the articulation of science education reform, little is known about how inquiry, a prominent feature of the current reform movement, is portrayed at conferences sponsored by these associations and how its portrayal shapes teacher thinking and classroom practice. What evidence of inquiry as a feature of science education reform would be encountered if investigating sessions presented at a conference sponsored by a state affiliate of NSTA?

To address part of this broad question, the present study examined the nature of inquiry-focused conference sessions and the thinking of session leaders. Future studies will address the effect of conference session participation on teachers' inquiry-related thinking and classroom practice. More specifically, this study interpreted the conceptions of inquiry evident in the experiences of eight professional development leaders who presented sessions at the 2007 Georgia Science Teachers Association (GSTA) conference. The GSTA is a state affiliate of the NSTA whose primary aim is to help prepare science teachers to "encourage the development of science interests and abilities as a vital part of the total educational development of students" (GSTA, 2005). In support of this aim, the association holds an annual leadership conference for Georgia science teachers. Each year, more than 500 science teachers participate in the conference. In 2007, 32 workshops or presentations, or about one out of nine conference sessions, included the word inquiry either in the title or program description. This study seeks to examine the nature of these inquiry-focused sessions and the session leaders' understandings of inquiry.

Drawing on interview data, artifacts collected during and following the conference sessions, and conference program descriptions, an emergent design led to the following guiding questions:

1. What is the nature of inquiry-focused professional development within the context of the GSTA conference?

2. What are the conceptions of inquiry held by the conference session leaders?

Conceptual Background

This work is grounded in understandings of professional development that support teacher growth and reform-based practice. Professional development for science teachers is conceptualized as a complex process of learning opportunities by which they develop "new knowledge, skills, approaches, and dispositions to improve their effectiveness in their classrooms" (Loucks-Horsley, Hewson, Love, & Stiles, 1998, p. xiv). Recent advances in thinking about science teacher professional development mirror reforms in science education, with greater emphasis placed on experiential learning, collaboration, and contextualizing the findings of research to address local issues and problems (Bell & Gilbert, 1996). Effective professional development for science teachers draws on a knowledge base that includes understandings about learners and learning, teachers and teaching, the nature of science, and the professional development process. Coupled with advances in thinking about professional development is greater attention to the relationship between teacher professional learning and student achievement (Penuel, Fishman, Yamaguchi, & Gallagher, 2007).

Professional development for science teachers can take many forms. One form is the conference, where teachers participate in short-term workshops and presentations of their own choosing. The most notable science teacher conferences held in the United States are those organized by the NSTA and its state affiliates. Assumptions that underlie this form of professional development include: sources outside of the teachers' normal sphere of influence can provide valuable knowledge; science teachers, as adult learners, benefit from engaging in professional learning experiences away from their classrooms; and the needs of many teachers can be met through a well-designed professional learning experience (Loucks-Horsley et al., 1998). Conference session leaders can facilitate teacher learning by presenting new ideas about content and pedagogy, demonstrating teaching strategies, and, when the session is organized as a workshop, providing opportunities for teachers to practice and discuss new knowledge and teaching strategies. Considered a traditional form of professional development, conference participation has inherent limitations when compared with reform-based models of science teacher professional development (Bell & Gilbert, 1996; Hawley & Valli, 1999). The most notable limitations are the short duration of sessions, the focus on discrete content and/or pedagogical learning goals, and inattentiveness to the participants' classroom context.

Two frameworks for describing professional development activities applied by Bredeson and Scribner's (2000) in their investigation of a statewide professional development conference may inform an investigation of inquiry-focused conference sessions. First, Schlechty and Whitford (1983) associate professional development with three functions: (1) an establishment function, where the purpose is to increase awareness of an educational program or procedure in order to promote change, (2) an enhancement function, for the purpose of improving teacher practice, and (3) a maintenance function, to promote continued practice and ensure the achievement of desired goals. Second, other researchers (Eraut, 1994; Marsick & Watkins, 1990) describe teacher professional development as potentially leading to the construction of propositional, procedural, and personal knowledge. Propositional knowledge highlights theoretical and content understandings, while procedural knowledge is that which is needed to perform effectively in practice. In contrast, personal knowledge includes the recollection of experiences and stories that may influence immediate practice. Schlechty and Whitford (1983) also identify political knowledge as a possible outcome of professional development. Here, political knowledge may be thought of in terms of how others successfully implement classroom inquiry in a climate of intense accountability and in the face of potentially skeptical administrators and fellow teachers.

An application of teachers' conceptual knowledge also guided this research. A principal tenet of this work is that every phenomenon can be conceptualized in various qualitatively different ways that are finite in number (Pang, 2003). Investigations that strive to articulate teachers' conceptions seek answers to the question: What are the ways a phenomenon is conceptualized? They emphasize the variation that researchers are able to detect in the different ways that teachers conceptualize phenomena. The goal of this research was to identify qualitatively different ways that teachers conceptualize their experiences with a phenomenon, where conceptions are formed as a result of directed attention toward particular aspects of the phenomenon. The products of this research are categories of description and the speculative relationships between the cat-

egories, collectively called the *outcome space* of the phenomenon (Marton & Booth, 1997). A conception "is taken fundamentally to concern the experienced meaning of one specific part of the surrounding world" (Svensson, 1989, p. 531). The term *conception of inquiry* as used in this work, refers to the meaning associated with inquiry and what constitutes inquiry-focused professional development in a science education context. Just as teachers' conceptions of inquiry vary and mediate their teaching practices (Lotter, Harwood, & Bonner, 2006), the conceptions of inquiry held by conference session leaders are considered to vary and are likely reflected in the nature of the inquiry-focused professional development experiences in which they engage teachers.

Historical and contemporary understandings of inquiry also informed our work. Inquiry is a complex process that has been defined in a number of ways (Abrams et al., 2007; NRC, 2000; Schwab, 1962). No single definition seems to capture all aspects of inquiry nor provide powerful guidance regarding its enactment in science classrooms. Inquiry is defined as both the way scientists study the natural world and as an approach employed in science classrooms to enable students to develop understandings of scientific ideas and the work of scientists (NRC, 1996). As a classroom approach, Schwab's (1962) conception of inquiry emphasizes the source of questions, data collection methods, and interpretation of investigative results across a continuum of teacher direction. Schwab's ideal for classroom inquiry is investigations initiated and carried out by students with minimal teacher direction. Inquiry in the classroom is also conceptualized as an inductive learning cycle, where student exploration with materials is followed by concept invention, elaboration, and evaluation (Bybee, 1997; Eisenkraft, 2003; Karplus & Thier, 1967).

Classroom inquiry is further viewed as being comprised of five essential features: questions, evidence, explanation, connections, and justification (NRC, 2000). These features are considered to vary along a continuum of student autonomy, depending on the instructional context. Settledge's (2007) examination of the presentation of the five essential features led him to describe inquiry as a set of mental and physical skills that students develop as they engage in science learning experiences. The five essential features also led Hammerman (2006) to generate a set of eight criteria for assessing the classroom implementation of inquiry. Finding direction in the science of ecology, Abrams et al. (2007) apply the analogy of ecological niche to explain the enactment of inquiry in a classroom context not as a static quality, but as having an optimal form, which is influenced by a number of resource axes. They suggest that the optimal form of classroom inquiry involves the intersection of resource axes that can be grouped into at least five conceptual categories: logistical, socio-cultural, abilities and knowledge, nature of content to be learned, and goals of inquiry. This presentation makes clear that classroom inquiry can take multiple forms. The goals of inquiry in school science may include learning about scientific inquiry, learning science content and utilizing science processes, learning about science as argumentation, and learning about the culture of science. Science teachers' conceptions of inquiry reflect many of the understandings presented in the historical and contemporary literature. Teachers think of inquiry primarily as instructional methods that can enhance student learning, with the use of questioning and student investigation as prominent features of classroom practice (Akerson & Hanuscin, 2005; Koballa, Atkinson, & Reeves, 2008).

In summary, the literature reviewed suggests that the conference is a pervasive vehicle for science teacher professional development and, conference session leaders, not unlike science teachers, may hold varying conceptions of inquiry. The literature is replete with different presentations of inquiry as applied in the science classroom, but provides little insight into the nature of inquiry-focused professional development within the context of science teacher conferences and conceptions of inquiry held by conference session leaders. Studying the nature of inquiry-focused conference sessions and the session leaders' conceptions will contribute to an understanding of how inquiry, a prominent feature of the current reform movement, is portrayed at conferences sponsored by state affiliates of NSTA and may suggest avenues for further investigation of how its portrayal in conference sessions shapes teachers' understanding of inquiry and their classroom practice.

Description of the GSTA Conference

The annual GSTA conference was held on February 15-17, 2007 at the Classic City Conference Center in Athens, Georgia. The conference consisted of more than 200 separate activities, including half-day and daylong tours, social functions, and plenary speeches in addition to concurrent presentations and workshops. An exhibit hall was also part of the conference and pro-

vided participants with access to textbook vendors and science equipment and material suppliers. Included in the conference program were 32 inquiry-focused concurrent sessions, of which eight (or 25%) were selected for study. The selected sessions are generally representative of the 32 in terms of grade level focus (i.e., elementary, middle, high), presenter gender and employment status (i.e., teacher, science professor, education professor, professional developer), and nature of the session as described in the conference program. The leaders of the selected sessions agreed to be interviewed about their sessions and conceptions of inquiry.

Data Sources and Analysis

This study was interpretative and guided by the phenomenological research tradition. According to Creswell (1998), phenomenology "describes the meaning of lived experience for several individuals about a concept or phenomenon" (p. 51). The phenomenological tradition is appropriate for studies that strive to understand the practical knowledge of conference session leaders as they engage others in professional development experiences. The search for understanding is embodied in our interest in identifying commonalities and differences in the session leaders' conceptions of inquiry as well as in the nature of the professional development experiences in which they engaged teachers at the conference. Interviews conducted with session leaders were triangulated with artifacts collected during and following the conference sessions and with session information presented in the conference program.

Interviews

A semi-structured interview protocol was developed and used to capture a broad range of information about inquiry and professional development from the session leaders. The eight participants included six females and two males. Of the eight, two are school science teachers, one is a university chemistry professor, one is a science education professor with high school teaching experience, and four are former science teachers working as professional developers. Interviews ranged from 30 to 65 minutes and engaged participants in discussion about their GSTA sessions, their conceptions of inquiry, and how inquiry was exemplified in their conference sessions. The interviews were conducted in the months following the conference.

Session Artifacts

Artifacts collected by the researchers during conference sessions and provided by the participants at the time of the interviews served as a secondary data source. The artifacts included handouts distributed at conference sessions and PowerPoint slides used during the sessions. Additional artifacts included session materials, such as balloons, string, and ping-pong balls, and instructional activities developed by participants for other purposes, but provided as evidence of the inquiry-focused experiences in which they engaged science teachers at the conference.

Program Information

Titles and descriptions of the participants' sessions were obtained from the 2007 conference program and added to the secondary data sources. The word inquiry appears in the title and description of sessions led by five of the study participants, in the title of sessions led by two participants, and only in the description of the session led by one participant.

Analysis Method

Cross-case inductive analysis (Patton, 2002) was employed to analyze transcripts of the interviews, session artifacts, and information provided in the conference program. Codes were generated based on our initial examination of these data; the codes were compared categorically and reduced to a smaller set that revealed patterns of inquiry-focused experiences. Categories were then generated that were strongly represented in the data from each participant. Descriptions and examples of the categories were provided to an external examiner for reliability purposes. This examiner, a science education professor with more than 15 years of teaching experience, independently scored the data with inter-rater agreement of 95%; disagreements between the examiner and researchers in category assignments were resolved by discussion.

The categories were related to the guiding questions and represented the broadest classification level. Using an inductive process, the codes were reapplied to the data for each session and leader by attending to the categories related to each of the two guiding questions. The results that follow reflect the categories and their associated codes. The eight session leaders reviewed their interview transcripts, with only one person offering comments that led us to refine the perspective depicted in the manuscript. All other participants thanked us for sending their interview transcripts and a draft copy of the manuscript to them for review and indicated that they agreed with the interpretations.

Results

The results are reported in two sections that corre-

Table 1
Characteristics of Inquiry Professional Development

Categories	Codes	Number of sessions
Session format	Interactive presesntation	1
	Modeling of classroom experiences (teachers take on role of students) and discussion	6
	Poster presentations	1
Portrayal of inquiry in session	Teacher-guided	8
	Teacher-initiated, but not teacher-guided (not student-initiated); full inquiry	1
Goal of session related to inquiry	Increase motivation for classroom inquiry	8
	Showcase teacher success with classroom inquiry	2
	Show inquiry as means to achieve desired instructional outcomes (e.g., close achievement gap, understand nature of science)	4
	Present inquiry as element of standards-based practice	2

spond to the two guiding questions. The results regarding the nature of the inquiry-focused sessions are presented first, followed by those about the session leaders' conceptions of inquiry.

Characteristics of Inquiry-Focused Sessions

The data summarized in Table 1 provide an image of the inquiry-focused professional development in which session leaders engaged teachers during the 2007 GSTA conference. Analysis of interview transcripts, session artifacts, and program titles and descriptions provides insight regarding the session format, how inquiry was portrayed in the sessions, and the relationship of inquiry to session goals.

Assertion 1: The conference session format primarily involved leaders modeling classroom experiences and discussing how inquiry is portrayed in the experiences.

The session format of modeling and discussing was employed in six sessions. This format allows leaders to emphasize the development of procedural knowledge (Marsick & Watkins, 1990) among teacher participants, knowledge that would enable them to better engage their students in science inquiry. Consistent with this format, the session leaders shared personal background information and described their teaching context. Then, they played the role of teacher while engaging the session participants in a learning experience similar to what is done with K-12 students, and concluded the session with a discussion of the experience. Mike[1] described the format in this way:

> During the session, I basically went through the class with them. I had an activity set up, introduced the lesson to them, mentioned the standard, and told them this is what we're going to do and how to do it. They went to work and I walked around with my checklist and asked the same questions that I would ask students. So, I was really sort of modeling what we do in our classrooms so that they would see how the inquiry method can be used to meet those standards.

Two other sessions used somewhat different formats. One session involved the leader engaging the teacher participants in an interactive presentation that centered on how inquiry-focused teaching could help close the science achievement gap. Macy, the session leader, explained, "I wanted to use the achievement gap as a way to discuss inquiry teaching in the classroom." In this session, Macy's presentation of science performance data for different groups of students coupled with discussion of the attributes of inquiry teaching led her to the proposition that all students will benefit from engaging in inquiry learning experiences. One other session, associated with a summer teacher enhancement project, used a poster presentation format. Here, the session leader orchestrated the poster presentations of eleven elementary teachers. As session participants rotated among the poster presentations in five-minute intervals, the elementary teachers illustrated and

described how they engage students in inquiry science and discussed challenges they encountered when engaging students in science inquiry and how they resolved them.

Assertion 2: Inquiry was primarily portrayed as a teaching method in the conference sessions, with opportunities for different levels of leader facilitation.

Leader facilitated inquiry was highlighted in all eight sessions as a method for guiding the professional development of teachers. Inquiry as portrayed in the sessions involved the leaders engaging session participants in activities that were "hands-on," "student-centered," and "concrete, visible and easy to manage." These activities were guided by "procedures" and involved "scaffolding" teacher learning. Leaders acknowledged the similarity between the experiences of session participants and what might occur in school science classrooms during the sessions and in interviews. Susan's explanation exemplifies this point.

> It would be very guided inquiry, so it is not the kind of inquiry that the kids go where ever they want to go as far as their learning. The topics are definitely given and it is definitely structured every day. Inquiry would come in where we encourage the kids to ask questions and be curious.

In two sessions, inquiry was also presented as a teaching method with opportunities for varying levels of teacher guidance and learner autonomy. For example, Amy explained to session participants how they could have their students experience inquiry differently using the same activity. Her session handout stated, "You may use this activity as an Open-ended Inquiry Activity or as a Guided Inquiry Activity by providing different procedures." Similarly, in Samantha's session, the elementary teachers who attended the summer teacher enhancement project and functioned as co-presenters, led session participants in activities that "started with guided inquiry and then we went all the way up to a point were we felt the teachers were then ready." As Samantha said, "This [our session] was a way to show that everyone does not have to teach or learn inquiry in the same way."

Assertion 3: The overarching goal for all the sessions was to increase motivation for inquiry teaching.

The goal of increasing motivation for classroom inquiry was pursued in the sessions by linking it to several enabling goals. These enabling goals offered teacher participants tangible reasons for engaging in classroom inquiry and provided them with samples of what inquiry might look like in science classrooms. In four sessions, inquiry was presented as a means of achieving desired instructional outcomes. Specifically, classroom inquiry was described as a way to close the achievement gap, correct learner misconceptions, and help students acquire content and better understand the nature of science. The program description for the session led by Macy is representative of those associated with increasing motivation for classroom inquiry by highlighting its potential for achieving desired instructional outcomes.

> Examine factors which research has shown to help close the achievement gap and how inquiry teaching can influence these factors.

A second way of addressing the goal of increasing motivation for classroom inquiry was to showcase leaders' successes with inquiry in their own teaching context. As a science department head at a new high school, Mike was able to tell participants that "we have it [inquiry teaching] in place as a school wide thing, and that makes a big difference" and to show them what inquiry teaching looks like in his classroom by engaging them in an activity in which students develop understandings about suspensions, solutions, and colloids. Similarly, Samantha's session gave elementary teachers, who participated in her teacher enhancement project, the opportunity to tell others about their classroom inquiry experiences and engage them in sample activities. A third way of addressing the goal was by presenting inquiry as an element of standards-based practice. In their sessions, Amy and Marie emphasized that meeting state standards requires "inquiry-based teaching". Marie summarized the events of her session in these words: "Participants conducted three tasks and then evaluated the tasks on a nine-point rubric related to the standards, and one of nine points was, Is the activity inquiry-based?"

Session Leaders' Conceptions of Inquiry

The data summarized in Table 2 indicate that the session leaders held varying conceptions of inquiry that they associated with multiple goals, characteristics, and barriers to classroom implementation.

Assertion 4: The most prominent conception of inquiry held by the session leaders is inquiry as a teaching approach.

Seven of the eight session leaders described inquiry as a teaching approach that involved teacher guidance. For these session leaders, "guided-inquiry" makes use of instructional models, procedures, or strategies that

Table 2
Conceptions of Inquiry Held by the Session Presenters

Categories	Codes	Amy	Haley	Macy	Mike	Marie	Susan	Samantha	Sam
Pedagogical approach (teaching)	Guided by teacher (scaffolding, 5E model)	X		X	X	X	X	X	X
	Open/full (teacher-initiated, but no teacher guidance	X			X				X
Learning approach (means by which students learn)			X	X		X			
Goal of classroom inquiry	Acquire content	X	X	X	X			X	
	Develop process skills		X			X			
	Promote sense-making		X					X	X
	Aid English languate learning		X						X
	Developing student interest		X				X	X	
	Develop nature of science understandings (inquiry into inquiry)						X	X	
Characteristic of classroom inquiry	Questioning (teacher initiates with questions, or leads students to questions		X	X	X		X	X	X
	Differentiated instruction	X	X	X	X				
	Activity-oriented (hands-on)	X		X	X		X		X
	Teacher acts as facilitator/guide		X	X	X		X	X	X
	Students follow procedures		X		X	X	X	X	
	Students design procedures and carry out investigation				X				X
	Student-centered	X	X						
	Hypothesis testing		X						
	Address science misconceptions		X				X	X	
	Student discovers concept (inductive process)			X	X				
	Teacher knows outcome (leading students to right answer)			X	X			X	

Table 2, continued

Categories	Codes	Amy	Haley	Macy	Mike	Marie	Susan	Samantha	Sam
Barriers to classroom inquiry	Time							X	
	Large class size							X	
	Equipment and supplies			X					
	Teacher comfort with inquiry (experience)		X	X		X			X
	Students have no/little experience with inquiry		X			X			
	Pressure of high-stakes testing						X		

steer the work of science teachers and their students. They associated guided-inquiry with teachers leading students to a predetermined outcome. Three of the session leaders' conceptions of inquiry as a teaching approach also addressed variation in teacher guidance. These session leaders used the terms, "open-inquiry," "full-inquiry," and "100% inquiry," to distinguish a teaching approach where teacher guidance is minimal or non-existent from "guided-inquiry." Sam's explanation is illustrative of the distinction made by the three teacher leaders.

> One thing that I associate with inquiry is that there can be several levels of inquiry. Sometimes there is need for much structure, where other times it is very open and students really construct all of their own questions and ways that they'll answer those questions. I just try to remember that inquiry can take several different forms, and sometimes it is more guided than others.

Three session leaders conceptualized inquiry as more than a teaching approach. Marie conceptualized inquiry as a teaching approach and as an approach to learning. She described inquiry as a learning approach as a way for people to "figure something out for themselves or come up with something for themselves that they didn't know before or find some way that it ties together." Similarly, Macy pointed out that inquiry is used to describe "two different things: one is the way we teach and the other is the way students learn." Haley conceptualized inquiry as only an approach to learning. Haley encouraged teachers to construct their own meaning from the observations they made when interacting with materials during her conference session. "To me inquiry is simply a process and an approach to make sense of the world around you." Haley was critical of individuals who conceptualize inquiry solely as a teaching approach and expressed concern about how instructional models, such as the learning cycle and 5E, are being used and viewed as inquiry, rather than as "scaffolding tools."

> I see inquiry much more as a learning method or as a habit of mind that teachers need to model, scaffold, and teach explicitly. Part of the confusion here is that when you present a program for teacher development, by definition your focus is on helping teachers teach rather than on helping student learn. You emphasize the role of the teacher in establishing and implementing the appropriate context for inquiry learning. For me, presenting inquiry as a teaching method, complete with 5Es or steps to follow, is antithetical to my conception of inquiry as a process of learning. Once again, inquiry as a teaching method becomes another thing done to kids instead of something done by kids.

Assertion 5: The session leaders' conceptions of inquiry include goals, characteristics, and barriers to classroom implementation.

The session leaders' conceptions of inquiry include six instructional goals. Foremost among them are the acquisition of science content knowledge and the development of student interest. When discussing inquiry in the context of his own classroom, Sam explained, "I found that students constructed their own meaning…and were able to retain and recall much more information." The leaders' conceptions of inquiry also included the instructional goal of developing understandings about the nature of science. Susan referred to this goal as having students learn how to "inquire into inquiry" and described how she would strive to achieve this goal in her teaching.

> Any time we write up a lab report in science, an activity of inquiring into inquiry would be to ask our self: Is our data valid? Have we really answered our question? And go back and think about it, is there any way that we could have improved our method? Were there any mistakes that we made in our inquiry process that would make our data not as trustable?

Six session leaders associated questioning with classroom inquiry. As Susan stated, "Inquiry is asking questions and trying to answer those questions." According to the session leaders, questions that launch investigative activities come from the teacher, but the investigations may lead to student questions about the topic under study. Also, six session leaders described the role of the teacher in classroom inquiry as "facilitator." The session leaders viewed the teacher as facilitator "guiding them [learners] along in the learning process" and one who "monitors the students carefully." Other characteristics that fewer session leaders associated with classroom inquiry were illuminating learners' misconceptions and differentiating instruction.

Barriers nested within the leaders' conceptions of classroom inquiry highlighted various aspects of their science-teaching context. The most prominent barrier was "teacher comfort with inquiry." According to Macy, "Inquiry teaching is kind of scary as a new approach." Other barriers included "class size," "pressure of high stakes testing," "time," and lack of equipment and supplies. As Mike stated, "you do need equipment and you do have to have a good supply of the things that kids will use in activities."

Discussion and Implications

This study explored eight inquiry-focused conference sessions and the session leaders' conceptions of inquiry within the context of a single state science teacher conference. While the selected sessions are similar to other inquiry-focused sessions presented at the conference in many ways, they were not formed as a representative or random sample, but rather, a convenient sample. As such, the findings of this study cannot be generalized to other conference settings. Nevertheless, it is believed that the findings contribute to an understanding of the professional development opportunities that are made available to teachers at conferences by providing insight into how inquiry, a prominent feature of the current science education reform movement, is portrayed at one conference sponsored by an NSTA state affiliate and the thinking of conference session leaders that likely influence this portrayal.

Conference Sessions

The results show that the foremost session format involved session leaders modeling classroom experiences. This underscores the centrality of the teacher's role in enacting inquiry in the science classroom and suggests that session leaders' draw on their own classroom inquiry experiences when engaging teachers in inquiry-focused professiónal development. Consistent with Anderson's (2007) description, the session leaders' portrayal of inquiry presents science learning as an active process with relationships between classroom inquiry and the ways in which scientists investigate the natural world. Further, the leaders' emphasis on teacher guided-inquiry in the sessions suggests that they consider it more suitable for the science classroom than other forms that provide for greater student autonomy.

Consistent with the leaders' reliance on their own classroom experiences to inform the professional development they provide, the conference sessions tended to highlight the usefulness of procedural knowledge over other knowledge types. This "how to" knowledge that teachers seemingly rely on to engage their students in classroom inquiry or other kinds of learning experiences is typical fare at science teacher conferences. Only the conference sessions led by Macy and Samantha appear to support other types of knowledge. Macy used propositional and political knowledge (Bredeson & Scribner, 2000) to argue for inquiry as a means of closing the achievement gap, and the elementary teachers who presented their posters in Samantha's session shared their personal knowledge (Eraut, 1994) of specific challenges encountered when engaging students in science inquiry and ways to overcome them.

The almost exclusive attention given to procedural knowledge in the conference sessions raises questions about session leaders' decisions to emphasize this knowledge type over others. Do most conference session leaders believe that teachers expect and will only benefit from sessions that emphasize procedural knowledge? Do they know how to build professional development that emphasizes combinations of propositional, procedural, personal, and political knowledge? Research is needed to learn more about conference session leaders' awareness of the different knowledge types described in the professional development literature (e.g., Eraut, 1994; Marsick & Watkins, 1990) and

the kinds of learning that teachers experience when different knowledge types are emphasized in conference sessions.

The overarching goal for all the sessions was to increase motivation for inquiry teaching. This goal seems to resonate with the short duration of the conference sessions. In increasing motivation for classroom inquiry, the sessions seem to serve both an establishment function and an enhancement function (Schlechty & Whitford, 1983). For teacher with little knowledge about how to engage students in inquiry experiences, the sessions may serve to increase their awareness of lesson ideas, materials, and programs useful for doing so. For other teachers with some knowledge of inquiry, the sessions may serve an enhancement function by offering suggestions for improving their effectiveness to engage students in classroom inquiry. None of the sessions seem to serve a maintenance function of ensuring the achievement of desired goals related to inquiry. Sessions did not provide teacher participants with opportunity for continued practice of inquiry-related understandings and skills. With each session about an hour long, what the session leaders could accomplish was indeed limited. However, there is no reason to believe that conference sessions cannot be organized and advertised as intending to serve an establishment, enhancement, or maintenance function. These different professional development functions could be described in conference proposal requests, as boxes to check on proposal forms, and used to designate sessions in conference programs, with the potential outcome of improving the value of conferences for science teachers.

Leaders' Conceptions of Inquiry

The results also provide insight into the conceptions of inquiry held by the conference session leaders. Primarily, the session leaders conceptualized *inquiry as a teaching approach*. They viewed inquiry teaching as encompassing a broad array of instructional models and strategies, and they rejected the notion of inquiry teaching as exclusively open-ended exploration. They viewed the teacher's role in the inquiry classroom as that of a learning facilitator. Scientifically oriented questions were the centerpiece of inquiry as a teaching approach, with questions used to initiate student engagement and viewed as welcomed outcomes of student investigation. Less conspicuous in the session leaders' conceptions of inquiry were the features of evidence, explanations, connections, and justification. Like questions, they are also considered essential features of classroom inquiry (NRC, 1996).

The session leaders' conceptions of inquiry included multiple goals for science instruction. Two of the goals described by the session leaders, using inquiry to learn science content and learning to inquire, are reflective of goals described in reform documents, specifically *Project 2061: Science for All American* (American Association for the Advancement of Science, 1989) and *National Science Education Standards* (NRC, 2000). One other goal prominent in the session leaders' conception of inquiry as teaching approach was the development of student interest. Unfortunately, the session leaders' adherence to the goal of science content learning seemed to be based on limited knowledge of the research indicating "the effectiveness of inquiry to engender student learning has been inconclusive" (Abrams et al., 2007, p. xvii). This may also be the case for student interest, as student interest generated through inquiry does not guarantee science content learning. Moreover, classroom experiences that highlight scientific inquiry may lead to student frustration rather than interest, particularly for those students who are comfortable as passive learners (Biological Sciences Curriculum Study [BSCS], 2005). These findings suggest that there is a need to learn more about conference session leaders' understandings about the benefits of classroom inquiry and the sources of these understandings. In addition, these findings challenge science educators to investigate factors at play when classroom inquiry is successful in promoting student engagement, interest, and positive affect.

The fact that three session leaders conceptualized inquiry as more than solely a teaching approach is noteworthy. For the session leaders who conceptualized inquiry as both a teaching and learning approach, it is possible that their conception of inquiry as a learning approach served to reinforce their conception of inquiry as a teaching approach, as Anderson (2007) envisioned for science teachers. Given this relationship, their conception of inquiry as a teaching approach may represent a compromise to conditions associated with the conference setting in which their inquiry-focused sessions were situated. Perhaps the conference conditions brought to the forefront a "working" conception (Samuelowicz & Bain, 1992) that mediated the professional development practices of the session leaders. When not focusing on the task of leading professional development for teachers in a conference setting, their conceptions of inquiry as a learning approach may become dominant. This compromising relationship seems consistent with the thinking of Haley, the session leader

who viewed inquiry as a learning approach and acknowledged that the focus of science teacher professional development in a conference setting tends to be more focused on teachers' teaching than on students' learning. The findings suggest that inquiry teaching and inquiry learning could be viewed as different sides of the same professional development "coin," and that the conference setting seems to bring focus to teaching over learning. With this in mind, session leaders should strive to acknowledge, if not emphasize, both inquiry teaching and inquiry learning in their work with science teachers. It is this dual emphasis that may lead session leaders to attend to inquiry-focused propositional, personal, and political knowledge in addition to procedural knowledge in conference sessions.

While not the focus of this study, the results suggest that the conceptions of inquiry held by session leaders may serve as referents for the professional development experiences in which they engage teachers. Considerable consistency seems to exist between the session leaders' prominent conception of inquiry and the ways in which inquiry was portrayed in their sessions. Future study should focus on the relationship between session leaders' conceptions of inquiry and their professional development practice.

Finally, it is important to note that misconceptions about inquiry-focused instruction identified as prevalent among science teachers by the BSCS (2005) are not part of the session leaders' conceptions of inquiry. For example, they do not consider inquiry-focused instruction the application of the scientific method nor do they believe that inquiry is the only way of teaching science. The leaders' sessions show that inquiry-focused professional development addresses science content and actively engages teacher participants. However, the session leaders' conceptions of inquiry and their professional development practices seem to present inquiry more as an alternative to other instructional strategies, such as lecture and demonstration, than as a core idea that is central to what science teachers do and how students learn. This study did not reveal that scientific argumentation, modeling, or the investigation of socio-scientific issues are elements of the session leaders' conceptions of inquiry, elements considered critical to productive participation in school science (Michaels, Shouse, & Schweingruber, 2008). Future studies of conference session leaders' conceptions of inquiry should probe for these elements.

Many science teachers participate in state science teacher conferences as a means of professional development. With inquiry at the center of today's science education reform, it is not surprising that inquiry is the focus of sessions at these conferences. Yet, the nature of these inquiry-focused sessions and the conceptions of inquiry held by the session leaders have not been extensively investigated. In fact, little is known about the nature of the professional development provided to science teachers at conferences sponsored by NSTA and its state affiliates. This study provides a snapshot of inquiry-focused professional development at one state conference, a view that reveals considerable commonality in session format and goals as well as in the ways in which inquiry is conceptualized by session leaders. The results of this study imply that inquiry-focused conference sessions can advance science education reform, particularly in providing teachers with access to procedural knowledge that may help them to engage students in classroom inquiry. More attention needs to be given to this form of professional development and its influence on the thinking and actions of science teachers.

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Authors' Note

[1] Pseudonyms ascribed to each participant

Exploring Middle School Girls' Science Identities: Examining Attitudes and Perceptions of Scientists when Working "Side-by-Side" with Scientists

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This article is the culmination of an extensive inquiry-focused interactive experience involving female middle school students and five university scientists, which demonstrated that middle school girls' perception of science and scientists can be successfully improved. The study exposed students to adult professional scientists over a period of a few days in laboratory and field exercises. Based on student journal entries and pictorial illustrations, as well as attitude surveys, the experience resulted in a keen appreciation of the sciences among the majority of participants and both a heightened and broadened awareness of Science as a Human Endeavor. The students' resulting perceptions reinforce the importance for science educators to expose their students to adult professional scientists in order for students, especially female students, to develop a better understanding of science and the role of scientists. Engaging scientists in helping promote science as a positive, exciting and satisfying career goal will help debunk common myths in the minds of young students about science and drive students, especially female students, to consider science careers.

Despite increases in the proportions of women in science and engineering careers over the last twenty years, these populations remain underrepresented (Eisenhart, Finkel, & Marion, 1996; National Science Foundation [NSF], 2003, 2006). Women's avoidance of science careers continue regardless of the increases in their participation and achievement in science courses (Gilbert & Calvert, 2003; NSF, 2003). The problem occurs when girls at a young age form perceptions about the human aspect of the sciences that are narrow and limiting, and unable to identify with science professions. The end result, unfortunately, is that young girls are turned off from the idea of becoming scientists.

Middle school girls are especially vulnerable as they are constructing their own identities. While some female students insist they are planning a science career, perceptions that surface in the fifth and eighth grades often times limit their pursuit of career choices in the areas of science and technology (Erb, 1981). Girls at this age often develop negative attitudes toward school science classes and science in general, which steer them away from considering science as a career (Kahle, 1990). Upon adolescence, students become more accepting in their views about jobs being performed by either sex, although girls show more flexible attitudes than boys (Entwisle & Greenberger, 1972).

Although research has provided some understandings of at what age and why some girls lose interest, the reality is we know very little about why or how some girls become more interested in science careers. Brickhouse, Lowery and Schultz (2000) and Kozoll and Osborne (2004) have linked identify formation as a critical dimension of how and why students engage in science, and therefore the focus of this study.

Science Identities

One's science identity, as defined by Carlone (2004) demonstrates competent performance in relevant scientific practices with deep meaningful knowledge and understanding of science, and recognizes oneself and gets recognized as "a science person" by others. The construction of this identity requires the participation of others as it is constructed socially within communities of practice (Tan & Calabrese Barton, 2007). Lave and Wenger (1991) concur students develop identities through engaging with the practices and tasks of the science class upon entering a community of practice such as the science classroom. Learning science in this community then becomes "a process of becoming to be, of forging identities in activity" (Lave & Wenger, p.3). The community of practice is dependent on environmental factors inherent within that community as it is accepted that these identities are fluid and subject to change. According to Brickhouse and Potter (2001) having a science or technology-related identity does not mean that one will necessarily succeed in school, if that science-related identity does not also reflect the values of the school-mediated engagement or if the students do not have access to the resources they need to do well in science. However, successful participation in school science, despite the lack of resources in a home

environment, can be better facilitated when students have a science-related identity they can draw upon. Clearly, there appears to be a complex relationship between identity and success in school. The purpose of this research study was to explore the complex relationship between science identities and other communities of practice besides the classroom setting.

Science Camp as a Community of Practice

"Side-by-Side" with Scientists was the community of practice identified for this study because of the environmental factors or the context in which these girls experienced science. How these young girls shaped their perceptions of scientists, and attitudes toward science as members of this community and how this relates to their overall science identities were the focus of this research. In order to gain insight into the girls' science identities their attitudes and perceptions regarding these experiences attitude surveys and drawings of scientists were employed two protocols not previously used in identity formation research. The critical difference and major significance of this investigation lies in the context of these protocols in relationship to girls' science identities. No study has previously used the drawings of scientists and attitude surveys to gain deeper insight into how young females science identities mature as a result of "Side-by-Side" experiences with real scientists.

The science camp was established to create a transformative experience for young female students in hopes of broadening their perceptions about scientists, where they work and what they do. Utilizing the principles of Science as a Human Endeavor (National Research Council [NRC], 1996), the roles of scientists and middle school girls were considered throughout the design and implementation process. Of the scientists participating in the study, four of the five were women and openly discussed their science identities and how they trained to become scientists.

At the science camp, middle school girls investigated real world problems in the areas of physical anthropology, chemistry, physics, geology, and biology. The girls spent each day, "Side-by-Side" with a different scientist investigating pertinent issues germane to that scientist's field of study. And at the end of each day, each scientist discussed career opportunities in their particular field and the girls reflected in their journals about each day's experience. The girls were encouraged to design and complete a science investigation in one of the five areas: physical anthropology, biology, chemistry, physics or geology following the camp.

Barriers Females Perceive about Sciences

Some of the stereotypes that deter intelligent young women from entering the sciences include the idea that "Science is for boys", "Science is boring", or "Science is too difficult". The development of negative attitudes toward school science is a reason why many students fail to participate in science courses beyond the basic requirements and refrain from entering scientific fields after school — especially females and minorities (Kahle, 1990). Parents, teachers and school administrators have unknowingly provided experiences for children that lead them away from, rather than toward, rich and rewarding experiences in science.

Negative attitudes toward school science originate and are reinforced from several sources, including the failure of parents to encourage their children to enroll in advanced science courses or pursue scientific careers (Tocci & Englehard, 1991), societal norms which govern the appropriateness of career selection to gender (Farenga & Joyce, 1998), teacher attitude (Brickhouse,1994; Jovanovic, Solano-Flores, & Shavelson, 1994; Kahle,1990; Plucker, 1996; Sadker & Sadker, 1995; Shepardson & Pizzini, 1992), and peer support (Simpson & Oliver, 1990). There also is a need to better understand females attitudes related to their perceptions of scientists in relationship to their own identities.

To address these barriers, it is suggested that girls develop a relationship with science role models (Betz, 1994; Hackett & Bentz, 1981; Hackett, Esposito, & O'Halloran, 1989; Lent, Brown, & Hackett, 1994; Nauta & Kokaly, 2001; Pleiess & Feldhusen, 1995; Zirkel, 2002), however, research in this area does not further science educators understanding of the process girls use in identifying with the science role models. Therefore, one of the purposes of this study was to explore the how science identities develop over a five-day experience "Side-by-Side" with scientists.

Females' Images of Scientists

Gender-stereotypical images have been reported for over fifty years in this area of research (Andre, Whigham, Handrickson, & Chambers, 1999; Brickhouse et al., 2000; Chambers, 1983; Kahle, 1983, 1987; Mason & Kahle, 1989). These images, of predominately masculine Caucasian scientists have long been an interest to teachers and researchers, alike, both to measure responses to instruction and because of the link between such perceptions and students career choices, as well as to understand attitudes toward science and self-efficacy in science courses (Finson, 2000; Schibeci, 1986). O'Brien, Kopala, and Mar-

tinez-Pons (1999) linked self-efficacy with respect to a given field with the probability of an individual choosing a career. Packard and Wong (1999) found this stereotype to impact girls' career choice negatively when images of themselves clashed with their gender-stereotypical image of scientists. Therefore, individuals who hold negative perceptions of science or scientists, and do not personally identify with scientists are unlikely to pursue science courses or select science as a career (Hammrich, 1997).

Smith and Erb (1986) suggested that if students encounter a variety of appropriate career role models in science, then the attitudes of both male and female students toward women in science would be positively affected. In order for this to occur we would expect that students have or are developing realistic perceptions of what constitutes science, who becomes scientists, and are also able to identify with scientists on a personal level. Unfortunately, student experiences with positive role models, as a way of developing more positive perceptions, remain largely unexamined. Exploring girl perceptions along these lines is important in understanding how perceptions are formed in the critical middle school years, the complexities surrounding the motivation of career choice and how to nurture girls aspirations, dreams, and talents in the direction of the sciences.

Research Questions and Methods

This research explores middle school girls' attitudes and perceptions regarding the nature of scientists in relation to their own identity. It draws upon qualitative and quantitative methods to address the following two questions (1) How do a select group of middle school girls' attitudes toward science change as a result of "Side-by-Side" experience? (2) How do a select group of middle school girls' perceptions of a) what scientists look like, b) where scientists work, and c) what scientists do change as a result of "Side-by-Side" experience?

Methods

The study was conducted at a major mid-western university during a summer camp experience. The participants ($N = 28$) consisted of female middle school students in fifth through ninth grades. The girls came from a variety of school experiences – public, private and home school and were invited to participate in the study because of their attendance at the "Side-by-Side" with Scientists' Camp.

Data collection included attitude surveys and journal responses for question one, and drawings of scientists and journal responses for question two. To address the first question, how the girls' attitudes changed as a result of the "Side-by Side" experience all girls participated in an Attitude Toward Survey (ATS) (Ledger, 2003) before and after the "Side-by-Side" experience. All surveys were analyzed using a t-test. The girls' journals were collected after the camp experience and coded by the researcher to support or provide evidence to the first question. In an effort to answer the second question, all girls participated in an Enhanced- Draw-A-Scientist Test (E-DAST) (Farland & McComas, 2006) before and after their "Side-by-Side" experience. All drawings were scored using the DAST Rubric (Farland, 2003) and labeled according to the DAST Continuum (Farland, 2006). Precautions were taken to ensure that participants were not provided additional directions or special instructions while completing either protocol. Once the above protocols were completed, they were sent to the researcher for scoring and analysis. The girls' journals were collected after the camp experience and coded by the researcher for analysis. Each instrument will now be described in full detail.

Attitude Toward Science Survey. The researcher used a modified form of the Student Opinion Survey (McMillan, 1992) developed by the Virginia Commonwealth University in conjunction with the Virginia Department of Education. The instrument was found to be valid and reliable, according to standards for test development for Education and Psychological Tests (Wagner, 1985).

The ATS questionnaire consisted of 10 questions. The questions required students to indicate strength of agreement with the statements provided, using a Likert scale. The survey can be found in Appendix A. The pre and posttests were analyzed using a two-tailed t-test.

The Enhanced Draw-A-Scientist Test. The students were given a piece of legal-sized white paper folded into three equal parts. They were instructed to place the paper so that only one box was visible. The following directions were read twice to students and the researcher did not elaborate beyond this specific prompt:

Imagine that tomorrow you are going on a trip (anywhere) to visit a scientist in a place where the scientist is working right now. Draw the scientist busy with the work this scientist does. Add a caption that tells what this scientist might be saying to you about the work you are watching the scientist do.

Students were instructed to draw a picture, using crayons, of a scientist in the single box visible to them.

At the same time, a research assistant monitored the class to ensure students drew only in one box and were working independently. When the students were finished, they were instructed to unfold the paper and draw two more scientists using the directions previously described. It is important to note that students did not know in advance that they would be asked to make multiple drawings. The E-DAST consists of a second page of four questions asking for specific information about the drawing. The children were asked: 1) Was the scientist you drew a man or woman? 2) Was the scientist you drew working outdoors or indoors? 3) What was the scientist doing in your picture? This set of questions was repeated three times, so students could answer a set of questions with each picture.

The researcher coded and scored the drawings using a scoring protocol called the DAST Rubric (Farland, 2003) in three specific categories: *appearance* (what the scientists looked like), *location* (where they worked) and *activity* (what they were doing). The DAST Rubric was applied to evaluate the three domains are described in Appendix B.

Each set of three pictures was labeled *Limited*, *Conflicting* or *Expansive*, based on the Draw-A-Scientist Continuum (Farland, 2006). The E-DAST Continuum was developed to express the range of perceptions that children hold about scientists. This tool also enables researchers to discuss the general themes of the cumulative children's drawings, and to identify the range of perceptions held by students. The total score is calculated for each category and labeled *Limited*, *Conflicting* or *Expansive*. If the drawing contains all the same stereotypical scientists in the picture, it is identified as *Limited*. If the drawing contains two or three very different conflicting images of scientists, it is identified as *Conflicting*. If the drawing incorporates three very broad, non-stereotypical perceptions, it is identified as *Expansive*. The domains of the DAST Continuum are fully described in Appendix C.

Results

The results of each question will be discussed independently, then the discussion session will meld these two questions in an effort to answer the overarching question of how does this information contribute to girls' science identity construction.

Question One: *How do a select group of middle school girls' attitudes toward science change as a result of "Side-by-Side" experience?*

A significant difference was not found when comparing the middle school girls' attitudes toward science before and after their "Side-by-Side" experience. The mean for the 26 girls (two were removed because they didn't complete the post-test) tested before the camp with a two-tailed t-test was 7.5. After the camp, the score was 7.7. It was determined that the sample was positive about science and scientists before the camp and remained positive after the "Side-by-Side" experience. The researcher then examined their journals for more evidence about how the girls' attitudes toward science developed over the course of the "Side-by-Side" experience. Some general comments from students in the study provide the impression that science is fun and interesting.

> …It is interesting because of all the tiny objects that live in the water that you wouldn't see unless you take close attention toward bugs. I also enjoyed looking through the microscope… I enjoyed it when we waded in the water and got water striders, fish and crawling water beetles. I thought it was fun to look at the different bugs, a bee, algae, a spider, and a crawling water beetle under the microscope. It was also fun to key in the bugs to find out what kind it was. Why I thought it was fun is because I like learning about all sorts of animals and I think they are just interesting.
>
> It's also cool that there are so many different parts of physics.

Some girls reported enjoying the independence in the design of the camp, and satisfaction in their own their learning process:

> ...I enjoyed that we could do pretty much everything independently. We could just read from the instructions and could just follow them on their own. I liked wearing the apron, goggles, and gloves, it made me feel so official. It was the best day of the week. I loved it a lot. I especially liked the experiments. They were all interesting and exciting. I loved it so much!!!! I especially liked the hair thing, blood and the chips experiment. That's pretty much everything.
>
> …I enjoyed learning more about things that affect me in everyday life. I enjoyed the pendulum and the prism because they are things I am interested in.
>
> …I enjoyed learning about physics because I

didn't really know much about it before today. I enjoyed doing the motion experiment. I didn't know all three balls moved at the same time. I didn't really enjoy it as much as the others, because I am not that into physics, although, most of it was still interesting.

...I will go home with a lot more knowledge than what I came in with this morning, thanks Dr. Geraldine.

Overall, the female students participating in the study left with positive impressions of science in general, as seen in the examples that follow.

...the chemistry day was the best because I never done anything involving chemistry before. And I didn't even know that was chemistry.

...Only in the movies and crime scene shows have I ever seen an ink print, so I thought that was cool to find what kind of fingerprint I had (spiral, loop, etc).

...I have enjoyed chemistry the most so far. Anthropology and physics do not interest me that much.

...I really don't like looking at bugs, but looking at their different parts, then keying them in was pretty cool. A lot of different creatures were found.

...I liked getting our microscopes today. It's so cool to think the smallest thing you can think of, when looked at through a microscope, looks huge with "even tinier" things on it.

One of the girls wrote about her stereotypical association between a laboratory and blowing up chemicals.

...I also liked working with chemicals (Amazingly, I didn't blow anything up). I liked pretending I was a real scientist figuring out a mystery. Everything else was really interesting too! I had a lot of FUN!

Only one negative comment was collected from the journals, and it was written in response to feelings about the day of physics activities.

...They should call it ALGA-BORIN!... (instead of algebra).

Question Two: How do a select group of middle school girls' perceptions of a) what scientists look like, b) where scientists work, and c) what scientists do change as a result of "Side-by-Side" experience?

This is a three part question because recent studies by the researcher (Farland, 2006) have provided evidence that children provide more information about how they perceive scientists than the previously established one drawing assessment. For example, when children of previous research studies were asked to "draw a scientist" (Chamber, 1983), they often included much more than appearance, which is not surprising as children often times are more willing to illustrate a thought as opposed to verbalizing a thought. It became evident that most students drew their scientists in particular places, doing particular activities. Based on these findings, it was determined that children are able to provide multiple perspectives – the *appearance* of scientists, the *location* where scientists work and the *activity* in which scientists are involved. Therefore, the results will discuss *appearance*, or what scientists look like first. Then, *location*, or where scientists work in the second part. Lastly, *activities*, or what scientists do in the third section.

All of these three are important to offer a comprehensive kaleidoscopic interpretation of how scientists perceive scientists. Unfortunately, only 20 sets of drawings were analyzed because eight of the students did not complete their posttest illustrations. The E-DAST Continuum was used to label the sets of drawings completed by the girls' both before and after the "Side-by-Side" experience. It is important to recall that each girl drew three pictures of scientists and these pictures were scored in three categories *appearance* (what do scientists look like), *location* (where do scientists work) and *activity* (what do scientists do). No cumulative score was given for each pretest or posttest, rather all three pictures in the pretest and posttest were scored according to *appearance*, then *location*, then *activity*. The DAST Continuum helps researchers make sense of the three pictures by assigning an average and a label for the three pictures. As previously mentioned this population was positively influenced by science enough to participate in the program, therefore, the results will focus on *Expansive* because this is the largest category identified and recall the goals of the study were to examine girls' perceptions who were already interested in science.

Appearance: Ninety-percent of the girls at the begin-

ning of the "Side-by-Side" experience drew their scientists in the most positive, broadest sense and their pictures were labeled *Expansive.* Following the "Side-by-Side" experience one hundred percent of the girls drew their three scientists in the broadest sense and their pictures were labeled *Expansive.*

The researcher then looked to the girls' journals for more clues about how their perceptions of scientists looked developed over the course of the "Side-by-Side" experience and one example response was selected to convey the idea that scientists sometimes work in teams.

> …I also learned how to part of a team doing a science experiment.

Location: More than half of the girls in the study (55%) had *Expansive* ideas about the places in which scientists work, meaning they had positive, broad ideas about the places scientists worked before the "Side-by-Side" experience. Seventy-five percent held *Expansive* ideas about scientists following the "Side-by-Side" experience. The researcher then looked to the girls' journals for more clues about how their perception of where scientists worked developed over the course of the "Side-by-Side" experience and one example response referred to the *location* of where scientists worked.

> …I found may things interesting about Dr. Darlene's research. One thing was that she travels all around the world studying primates. I think that is AWESOME! Another thing is that she always tries to prove her hypothesis right. I also think she knows so much about apes and monkeys and is really cool. It would be really fun to be a physical anthropologist…

Activity: More than half of the girls participating in this study (55%) also held positive, broad, or *Expansive* ideas about the activities scientists do before the "Side-by-Side" experience. Sixty percent of the students held Expansive ideas about the activities of scientists following the "Side-by-Side" experience. The researcher then examined the girls' journals for more evidence about how their perception of what scientists do developed over the course of the "Side-by-Side" experience and only one response discussed the detailed aspects of scientist work.

> …One thing that was neat about her job was though there was such a broad field to begin with, her actual job (what she does) is so narrow. She studies vocal reactions of primates. I would have never known that someone would do <u>just</u> that for a career. Some people might think primates just hoot, but for them it's a whole language. It is like we speak English, German, etc.

Some of the girls commented about the *activity* in terms of their own career identity.

> …I think her job is very exciting. I really like monkeys (but) it was kind of scary when she told us that this guy got attacked by one. I am not sure if when I grow up I want to do things with science or not. I am very excited to do more stuff here.

> …Dr. Darlene's is interesting, but not something I'd ever choose as a career.

> …The second experiment told me that weight does not matter. I found the third experiment interesting because the little hole works like a human eye. It is not something I would pursue as a career.

> …I enjoyed testing different bloods and looking under the two-eyed microscopes at the different hair types. I think Dr. Francene's job is cool.

Several of the girls reflected on the *activities* of scientists as it relates to scientific methods.

> …Also, I learned you need to perform an experiment numerous times to support the idea (not prove it though).

> …I learned how important it is to make experiments balanced. The dog experiment showed me how untrustworthy experiments can be when variables are present and cannot be removed or changed… That you can actually go out and test your hypothesis if you've got one. I never knew that anyone can actually do that as a job. Also, I didn't notice how alike all the primates' expressions were, and that they can tell in detail other animals' sounds. Hiding a camera in a bush is a good idea. You can get a lot of good recordings (and photos) that way. Dr. Darlene's job sounds like a lot of fun.

> ...I found many things interesting about Dr. Darlene's research. One thing was that she travels all around the world studying primates. I think that is AWESOME! Another thing is that she always tries

to prove her hypothesis right. I also think she knows so much about apes and monkeys and is really cool. It would be really fun to be a physical anthropologist.

...By doing the dog experiment I learned how to set up an experiment, record an experiment, and how to run an experiment in general. It was really fun. Dr. Darlene helped us a lot. I also learned things that will help me in the future if I become a scientist. I hope I will get to do some more experiments.

I learned that there were many ways to measure data. Also, that when doing science research that there are a lot of things to consider such as fairness, problems, scenery, and your data matching your predictions pretty much or exactly. I also learned that science may have a lot of work but is amazing the things you learn about yourself and the animals around you or far away. I also learned that collecting data is a whole lot of fun when you do it in a group of people. I never really liked science but I think it is such a cool subject. I think science is so cool because you learn about new things that nobody knows or has ever even heard about before.

These results reinforce the idea that a child can hold a range of perceptions, (Farland & McComas, 2006) and that the "Side-by-Side" experience may have caused students to sway toward the, broader, more positive, *Expansive* images. What is important is that this research demonstrated middle school girls' perceptions about the *appearance*, *location*, and *activities* of scientists can be maintained or improved as a result of the "Side-by-Side" experience. The comments made by the girls reinforced the fact that they were reflecting on their experiences of seeing a variety of scientists, in a variety of locations, doing a variety of activities. Even though these questions were not directly asked to the participants, the themes of personal identification were evident in their reflections and seemed to surface almost naturally.

Discussion

How did these interactions with a variety of science role models contribute to middle-school girls' science identities? The results from the ATS and E-DAST indicate that the girls who began their "Side-by-Side" interactions with positive attitudes and healthy, realistic perceptions of scientists, maintained or improved these perceptions after their experience with a variety of science role models. Experiences with these science role models appeared to cause the girls to search their own identities in the process of identifying if they could picture themselves in a particular science career. For example, excepts from journals highlighted the girls' perception that what a particular role model may do for a career may be exciting, along with the interpretation that they couldn't see themselves doing it. For this reason, the introspective nature of their science identity must be contextualized within their own identity in order for it "to fit," or seem like a plausible career. This is a similar finding to the study in which Packard and Wong (1999) used interviews to conclude that if images of scientists clashed with images of themselves it had the potential to impact the career choice negatively. However, in this case, using journal reflections, the girls' were able to maintain their positive ideas about science and scientists and simply suggest, "I could or could not see myself in this role."

Two questions were the focus of the five-day "Side-by-Side" with scientists exposure. The first question focused on the girls' attitudes toward science. It should not come as a surprise that the majority of girls who volunteered to participate in this "Side-by-Side" experience had positive attitudes before the experience and their perceptions remained positive immediately following the "Side-by-Side" interaction. Smith and Erb (1986) suggested that if students encounter a variety of appropriate career role models in science, then the attitudes of both male and female students toward women in science would be positively affected. This study concurs with that research and broadens it to include if positive students who report 'liking science' encounter a variety of appropriate career role models, then their attitudes toward women and science would continue to be positively affected.

Comments from the girls' journals responses referred directly to the enthusiasm and excitement of learning specific subjects like, chemistry or physics and their enjoyment of leading their own investigations. This community of practice was a unique setting, as it appears the girls' positive attitudes about science and scientific activities created a community of girls who felt confident, and were excited for the next day's challenge. In these ways the "Side-by-Side" experience seemed to solidify the girls' attitudes and create a contagious atmosphere among the girls, such is typically not the case in the regular classroom. This researcher

has no way of knowing how this atmosphere influenced their science identities and should be the focus of future research. These results are important because this study demonstrates that placing girls in environments intentionally designed to broaden their perceptions along with their positive attitudes does help to benefit them and in this case, helped to deepen and foster those positive attitudes and while the girls shaped their own identities along with that of a variety of scientists. Only future studies about the longitudinal effect of this experience will be able to inform educators about how these positive attitudes contributed to their classroom experience and or their career goals.

Student experiences of this nature can be a huge benefit in exciting female students about science and the possibility of pursuing careers in science – careers that are experiencing a dramatic loss of interest among women. It cannot be assumed that the perceptions of the girls in this study will remained changed forever, but this study does indicate that "Side-by-Side" interactions with scientists as a community of practice, can help students attitude toward science and scientists in deeper, more meaningful terms.

The second question examined the girls' perceptions of scientists in three areas *appearance*, *location* and *activity*. Students are influenced not only by the personal images they hold of scientists, but by the content of the science courses they experience in schools. Traditionally, the overwhelming emphasis in science education has centered on mastering a designated body of knowledge. Consequently, students have obtained a narrow and somewhat erroneous impression of science and scientists. It is an important finding that these particular girls were able to refine and shape their perceptions of scientists more positively and broadly after a variety of "Side-by-Side" experiences. Furthermore, it confirms that perceptions of scientists can be changed and that students can develop a healthy, broad perceptions of scientists, along with an appreciation of Science as a Human Endeavor, which is a crucial element in the *National Science Education Standards* (NRC, 1996). Because it is now understood that a child can hold a range of perceptions (Farland & McComas, 2006), this experience may have caused girls to create more *Expansive* images, where ultimately, we hope more students will develop mature, realistic perceptions of scientists.

Recall that the construction of one's science identity requires the participation of others as it is constructed socially within communities of practice (Tan & Calabrese Barton, 2007). Therefore, we do not have any idea how these broadened science identities will change when they return to school settings as it is accepted that these identities are fluid and subject to change. This is an area of future research.

When these girls go back into their school settings and home environments will they maintain the competent performance in relevant scientific practices with deep meaningful knowledge, understanding of science, and recognize herself and gets recognized as "a science person" by others? Will these experiences of the "Side-by-Side" interactions with a variety of science role models be enough of a science-related identity they can draw upon as they face the barriers educational researchers often discuss (school, parents, environment, peers)? These are all questions for future research.

It is important to remember that this research demonstrated that middle school girls' perceptions of what scientists look like, where scientists work, and what scientists do, can be influenced and improved even among girls who are already interested in science. Using instruments like the DAST Rubric and DAST Continuum can assist educators and education researchers to track the progress of changes in student perceptions and ultimately one's science identity.

Although research has provided some understandings of at what age and why some girls lose interest, this research address the gap to a deeper understanding of why or how some girls become more interested in science careers. Considering most of the work in this area of research is conducted with middle school girls in urban settings, this study also provides a new perspective. It is unique because it assembled four critical lenses to view how girls become even more interested in science careers, the framework of identity formation, the use of science role models, examination of attitude toward science, and multiple perceptions of scientists to provide new information about the importance of communities of practice in helping students to create positive impressions about scientists and science. Experience such as "Side-by-Side" interactions can be invaluable in fostering future career choices in science to girls and provide them with an accurate and favorable perception of scientists in the world today, while increasing their positive attitudes toward science and scientists.

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Appendix A

Attitude Toward Science Survey

Place an "X" in the box which expresses how you feel. Your number is _____

Question Number	Statement	Always (A)	Almost Always (AA)	Sometimes (S)	Never (N)
1	An understanding of science is important.				
2	Understanding science helps me to understand what happens around me.				
3	Science is useful to people whether or not he or she wants to be a scientist.				
4	I spend extra time reading about science topics.				
5	It is important for me to be good at science.				
6	The things I learn in science are important to me now.				
7	The things I learn in science class will help me later on in life.				
8	I like to find out new ideas and discoveries in science.				
9	I can become a scientist if I want to.				
10	I plan to have a career in science in the future.				

Appendix B

Description of Scoring Categories in the DAST Rubric

The *Appearance* Category

If a category is labeled Limited, it means the child illustrated a narrow representation of the category. For example, if a child's cumulative *appearance* category is labeled Limited it means that the cumulative score of all three pictures was between a 3 and a 4.5 in this category and suggests the child drew very similar appearances of all three scientists. Most likely, the child drew very stereotypical *appearances* of scientists on each opportunity. If a child's cumulative *appearance* category is labeled Competing it means that the cumulative score of all three pictures was between 4.5 and 7.5 and suggests that the child drew very different holds very different perceptions of scientists which compete within their understanding of what scientists look like. Most likely, the set of three pictures include a stereotypical representation of the *appearance* of a scientist and a non-stereotypical representation of the *appearance* of a scientist. If a child's cumulative *appearance* category is labeled Expansive it means that the cumulative score of all three pictures was between 7.5 and 9 and suggests the child holds very robust ideas about the *appearance* of scientists. Most likely, they included women in their pictures, or multiple scientists in more than one picture.

The *Location* Category

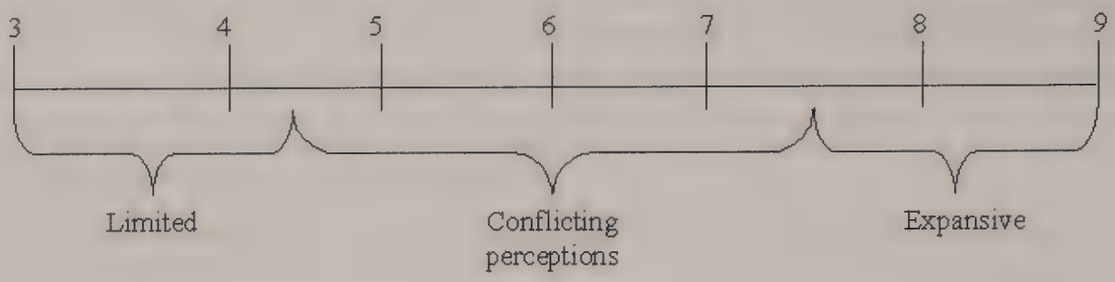
If a category is labeled Limited, it means the child illustrated a narrow representation of the category. For example, if a child's cumulative *location* category is labeled Limited it means that the cumulative score of all three pictures was between a 3 and a 4.5 in this category and suggests the child drew very similar location in all three pictures. Most likely, the child drew very stereotypical *locations*, like basements, of scientists on each opportunity. If a child's cumulative *location* category is labeled Competing it means that the cumulative score of all three

pictures was between 4.5 and 7.5 and suggests that the child drew very different holds very different perceptions of the places where scientists work. Most likely, the set of three pictures include a stereotypical representation of the *location* (basement) of a scientist and a non-stereotypical representation of the *location* (outdoors) of a scientist, or just had three traditional pictures of a scientist working in a laboratory setting. If a child's cumulative *location* category is labeled Expansive it means that the cumulative score of all three pictures was between 7.5 and 9 and suggests the child holds very robust ideas about the *location* of scientists. Most likely, they included the possibilities of outdoors into their perception of where scientists work, and carried this through to more than one picture.

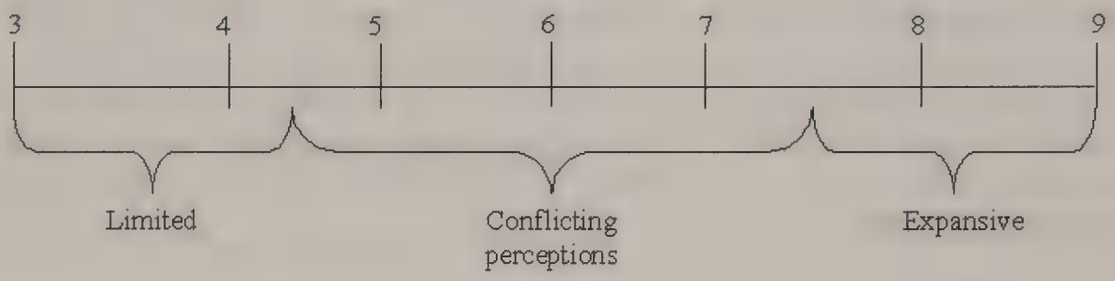
The *Activity* Category

If a category is labeled Limited, it means the child illustrated a narrow representation of the category. For example, if a child's cumulative *activity* category is labeled Limited it means that the cumulative score of all three pictures was between a 3 and a 4.5 in this category and suggests the child drew very similar *activities* of all three scientists. Most likely, the child drew stereotypical representations of the *activities* done by scientists on each opportunity. If a child's cumulative *activity* category is labeled Competing it means that the cumulative score of all three pictures was between 4.5 and 7.5 and suggests that the child drew very different holds very different perceptions of the *activities* done by scientists, which compete within their understanding of what do. Most likely, the set of three pictures include a stereotypical representation of the *activity* of a scientist and a non-stereotypical representation of the *activity* of a scientist. If a child's cumulative *activity* category is labeled Expansive it means that the cumulative score of all three pictures was between 7.5 and 9 and suggests the child holds very robust ideas about the *activity* of scientists. Most likely, they included women in their pictures, or multiple scientists in more than one picture.

E-DAST Individual Continuum:
APPEARANCE



E-DAST Individual Continuum:
LOCATION



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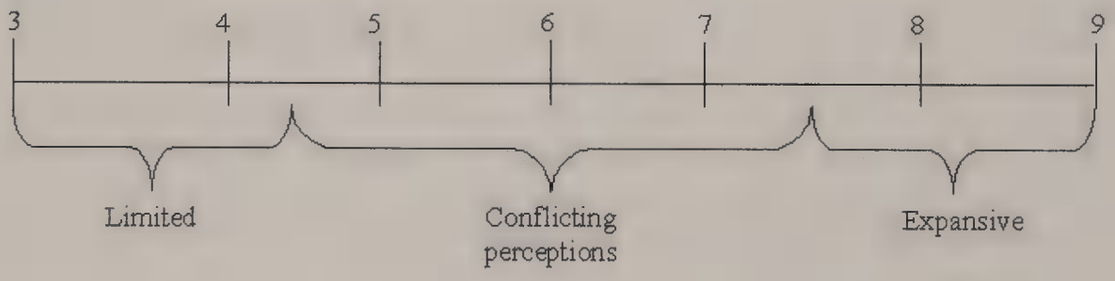

Formative Assessment: Improving Learning in Secondary Classrooms

Author: Center for Educational Research and Innovation [CERI]

OECD
2 rue Andre-Pascal
75775 Paris Cedex 16
France

2005; 279 pages
ISBN 92-64-00739-3

Reviewer: Dr. Mehmet Aydeniz
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Knoxville, TN 37996-0001

The language of reform has been a hallmark of education for the last century or so. Reforming school systems, standards, curriculum, and teacher education has been the highlights of reform policy in education. In fact, educators have made some significant progress in terms of dealing with the issues of school systems, curriculum development, and professional development. Although reform-oriented methods of assessment are as important as reformed curricula and reform-based teaching strategies, assessment reform has received the least attention. Unfortunately, our understanding of assessment in the context of educational reform has been limited to the improvements to some psychometric attributes of standardized tests and end of unit classroom tests.

Although educators have talked about the role of alternative assessments in improving students' learning across curriculum, little attention has been paid to the structures that facilitate or constrain the enactment of assessment reform in the classroom (Aydeniz, 2007; National Research Council, 2001). Several educators have recently argued that traditional classroom assessments, which rely on one-time end of unit evaluations, provide information that is of limited use to the students who are engaged in learning and to the teachers who are engaged in adjusting their instruction to meet the learning needs of their students (Black & Wiliam, 1998; Boston, 2002; Crooks, 2001). These educators have argued that formative assessment strategies are more powerful than the traditional assessments for improving the quality of students' learning and the effectiveness of instruction, therefore, they must be widely used by classroom teachers (Aydeniz; Shepard, 2000; Stiggins, 1999). However, multiple factors that exist at the policy level, school system level and classroom level discourage teachers from integrating formative assessments into their everyday practice (Herman, Ashbacher, & Winters, 1992). These factors include but are not limited to the fate that the policy makers have in high-stake standardized tests, teachers' limited literacy in assessment strategies and teachers' commitment to content coverage with limited attention to the depth of content covered.

The book, Formative Assessment Improving Learning in Secondary Classrooms makes the case for the widespread use of formative assessments in the classroom by bringing answers to all of these questions under close scrutiny. The book brings exemplary cases from different countries to the readers' attention, opening the door for the possibility of widespread use of formative assessment methods in the secondary school classrooms. The book discusses this possibility in light of the political and practical challenges.

The book consists of three parts. Part I focuses on defining the elements of formative assessments and making the case for formative assessment by bringing perspectives from policy, classroom and research. The first chapter focuses on answering the question of "Why use formative assessment?" The book advocates that formative assessment improves the quality of learning, (1) by placing the emphasis on the process of learning and teaching rather than on the outcomes of teaching as measured through end of unit assessments, (2) formative assessments metacognitively engage students by giving them a greater role in their own learning and (3) it fosters' students' ownership over their learning by engaging them in peer and self assessment. This book examines a wide range of policies that are designed to promote the widespread use of formative assessment strategies across case study countries. The first chapter is of great use to policymakers as it dis-

cusses the policies that shape curriculum guidelines, assessment culture within wider educational systems and how to structure incentives for teacher professional development.

Part II focuses on examining cases from classrooms across case-study countries and brings the benefits for student learning, barriers and opportunities for classroom practice to the readers' attention. As this book brings cases from various countries to the readers' attention, it provides the opportunity for educators to learn about what works, the possible barriers to wider practice and ways to overcome those barriers.

Part III. is an analysis of existing research on formative assessment. Part III consists of six sections. Section I provides the analysis of research that provides evidence on the effectiveness of formative assessment strategies on students' learning gains. This sections is very instrumental to those who are not yet convinced of the impact of formative assessment strategies on the quality of students' learning. This section makes it the case as to why formative assessments bring about changes in the learning of students and especially of those who have historically failed in learning school curriculum.

Section II focuses on formative assessment practices of classroom teachers. The analyses reveal that teachers hold a naïve view about the role of formative assessment in student learning. The authors also state that current formative assessment strategies employed by teachers do not reflect the deep changes envisioned in teachers' classroom assessment practices. This is problem because the issue has not been resolved even at the conceptual level. For instance, educators have interchangeably used the terms alternative assessment and formative assessment. Failing to distinguish between formative assessment and alternative assessment methods can lead to many misconceptions about assessment of learning and subsequent teacher practice. Section III focuses on analyses of research that looks at students' involvement in assessment of their own learning. This section focuses on examining students' learning goals, their motivation to learn, conditions and assessment practices that empower them to intrinsically engage in learning and those that marginalize them in the classroom. Section IV provides an analysis of existing research that holds a great potential for teacher learning. The analysis focus on ways to create a classroom discourse that makes the use of formative assessment strategies appealing to the teachers. It also discusses the potential benefits of such classroom discourse for student learning. This point is very important because many teachers have misconceptions about formative assessments. For instance, many teachers believe that alternative assessments take too much class time for the amount it takes to design and implement them (Duschl & Gitomer, 1997). This chapter addresses these concerns.

Section V provides an analysis of formative assessment in the broader context of teaching and learning. The discussion focuses on how different perspectives on teaching and learning liberate or constrain the frequent use of formative assessment strategies in the classroom. The analyses reveal that the frequent and adequate use of formative assessment strategies exist in classroom discourses that focus on students' mastery learning than those that focus on students' acquisition of factual information. The analyses in Section VI focus on the conceptual definition of feedback, how it has been utilized and the benefits for students' learning.

Over all this book is a must read for educators who are interested in the use of formative assessment in the classroom, school administrators who are interested in making formative assessment strategies as part of their school's evaluation culture and researchers who want to examine the impact of formative assessment strategies on students' learning gains.

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Archimedes to Hawking

Author: Clifford Pickover

Greenwood Press
88 Post Road West
Westport CT 06881

2007; 216 pages
Hardback $49.95

Reviewer: Robert J. Whitaker
Missouri State University
Springfield, MO 65897

Everyone has had the experience of looking for something in an encyclopedia or almanac and an hour later still browsing after one had found the original item. *Archimedes to Hawking* is that kind of a book. We encounter, particularly in physics, a collection of "laws" bearing the names of those who formulated them. These include, for example, "Kepler's Laws," "Boyle's Law," "Coulomb's Law," "Ohm's Law," "Hubble's Law," and so forth. The author has collected approximately forty of these and has provided brief discussions of the "laws" and short biographies of the individual associated with each. References and "Interlude: Conversation Starters"—brief quotations related to the nature of science—conclude each section.

The author prefaces this collection with a discussion of the nature of "laws." He notes that all of his examples involve laws. These "laws" describe the relationship between (or among) variable(s) based upon experiments of a particular phenomena (such as "Boyle's Law") or upon observations (such as "Kepler's Laws").

He then examines the relationship of "laws" to "theories" and refers to John Casti's discussion in the first chapter of his *Paradigms Lost*. However, Casti summarizes a number of philosophical positions concerning the nature of "theories." Pickover seems to have selected one that suggests that the scientist goes from observations to hypotheses through experiments to laws and then to theories. Readers will recognize this as a classic description of "the Scientific Method" that prefaces many science textbooks. The questions that should be examined and discussed by the reader is "Do scientists *do* this?" And, "Do the author's examples *demonstrate* this?"

It is, perhaps, misleading to suggest that all science involves experimentation. For example, Max Planck's first attempt at solving the problem of blackbody radiation involved fitting a curve to the empirical data, but his subsequent theoretical derivation introduced concepts that were totally at odds with experimental understanding and with all theoretical approaches of his time. That his approach worked was disconcerting to him and to his contemporaries. One might look for examples in the work of other theoreticians.

Many of the quotations come from scientists, and one might wish for fuller documentation of their source. The biographical references to the *Dictionary of Scientific Biography* are valuable, though one might wish for some additional recent historical references where available. The author's comments and the examples that follow should lead to debate among critical readers. If he has been successful in this, the reader will have gained a greater understanding of the nature of science and will be encouraged to seek greater depth and further historical perspective in other resources.

PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to: Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel; or fax to:972-86-477-648. Questions concerning proposals and/or solutions can be emailed to: eisenbt@013.net. Solutions to previously stated problems can be seen at: ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before January 15, 2010

5080: *Proposed by Kenneth Korbin, New York, NY*

If p is a prime number congruent to 1 (mod4), then thre are positive integers a, b, c, such that

$$\arcsin\left(\frac{a}{p^3}\right)+\arcsin\left(\frac{b}{p^3}\right)+\arcsin\left(\frac{c}{p^3}\right)=90°.$$

Find a, b, and c if $p=37$ and if $p=41$, with $a<b<c$.

5081: *Proposed by Kenneth Korbin, New York, NY*

Find the dimensions of equilateral triangle ABC if it has an interior point P such that $\overline{PA}=5, \overline{PB}=12,$ and $\overline{PC}=13$.

5082: *Proposed by David C. Wilson, Winston-Salem, NC*

Generalize and prove:

$$\frac{1}{1\cdot 2}+\frac{1}{2\cdot 3}+\cdots+\frac{1}{n(n+1)}=1-\frac{1}{n+1}$$

$$\frac{1}{1\cdot 2\cdot 3}+\frac{1}{2\cdot 3\cdot 4}+\cdots+\frac{1}{n(n+1)(n+2)}=\frac{1}{4}-\frac{1}{2(n+1)(n+2)}$$

$$\frac{1}{1\cdot 2\cdot 3\cdot 4}+\frac{1}{2\cdot 3\cdot 4\cdot 5}+\cdots+\frac{1}{n(n+1)(n+2)(n+3)}=\frac{1}{18}-\frac{1}{3(n+1)(n+2)(n+3)}$$

$$\frac{1}{1\cdot 2\cdot 3\cdot 4\cdot 5}+\cdots+\frac{1}{n(n+1)(n+2)(n+3)(n+4)}=\frac{1}{96}-\frac{1}{4(n+1)(n+2)(n+3)(n+4)}$$

5073: *Proposed by José Luis Díaz-Barrero, Barcelona, Spain*

Let $\alpha>0$ be a real number and let $f:[-\alpha,\alpha]\to\Re$ be a continuous function two times derivable in $(-\alpha,\alpha)$ such that $f(0)=0$ and f'' is bounded in $(-\alpha,\alpha)$. Prove that the sequence $\{x_n\}_{n\geq 1}$ defined by

$$x_n \begin{cases} \sum_{k=1}^{n} f\left(\frac{k}{n^2}\right), & n > \frac{1}{\alpha}; \\ 0, & n \le \frac{1}{\alpha} \end{cases}$$

is convergent and determine its limit.

5084: *Proposed by Charles McCracken, Dayton, OH*

A natural number is called a "repdigit" if all of its digits are alike.
Prove that regardless of positive integral base b, no natural number with two or more digits when raised to a positive integral power will produce a repdigit.

5085: *Proposed by Valmir Krasniqi, Prishtinë, Kosova*

Suppose that $a_k, (1 \le k \le n)$ are positive real numbers. Let $e_{j,k} = (n-1)$ if $j = k$ and $e_{j,k} = (n-2)$ otherwise. Let $d_{j,k} = 0$ if $j = k$ and $d_{j,k} = 1$ otherwise.

Prove that

$$\prod_{j=1}^{n} \sum_{k=1}^{n} e_{j,k} \alpha_k^2 \ge \prod_{j=1}^{n} \left(\sum_{k=1}^{n} d_{j,k} \alpha_k \right)^2.$$

SSM Publication Guidelines

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No. of in-house reviewers: Up to three
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Invited articles: 5% or less

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Source of publication guidelines: Publication Manual of the American Psychological Association, 5th Edition.

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Manuscript preparation:

All manuscripts must be prepared according to the 5th Edition of the Publication Manual of the American Psychological Association, typed double-spaced using a 12-point or larger font, and printed on 8 1/2- by 11-inch paper. Manuscripts should be limited to 25 pages, excluding figures, tables, and appendices. **Submissions that are not APA style or exceed the length limitation will be returned.**

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1. An abstract not to exceed 200 words on a separate page
2. To maintain anonymity of the author(s), author(s) citing their own work should cite as follows:
   In text: Author (1999) found...
   On reference list: Author (2005). Journal Title. (Do not include title of article or volume and page #)
3. Graphics submitted as publication-ready copy on white background with black type. Each table or figure should be on a separate page at the end of the manuscript, with a note within the ms where the graphic should be placed. Use no smaller than 8-point font for text on figures; use no smaller than 11-point font for tables. Figures and tables should be no wider than 6.75 inches.

Manuscripts submitted for review will be evaluated on the following:

All manuscripts:

Relevence, timeliness, and significance
Addresses K through graduate classroom or teacher education issues
Explicitness, clarity, logicality, conciseness
Literature review
Theoretical/literature-based framework

Research manuscripts only:

Design and methodology
Analyses of data
Conclusions based on results
Results related to professional practice and literature
Enough information to enable replication (quantitative)

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IN THIS issue

Research Articles

The Frequency, Variation, and Function of Graphical Representations within Standardized State Science Tests

Yi-Fen Y. Yeh, Erin M. McTigue

The purpose of this study was to determine the extent that diagrammatic literacy is necessary for success on standardized science tests at the late-elementary and middle grade levels. Towards this goal, we quantified the frequency, form and function of graphical representations on select state science tests. 985 tests items from 14 states were analyzed with 52.7% of the test items including graphical representations. The majority of these graphics, 79.5%, contained information that was essential for correctly answering the questions. The paper also discussed the trends of graphical representations in grade levels and alignment to national standards, following with teacher-implications.

The Relationship Between Lesson Study and Self-Efficacy

Tim Sibbald

This article addresses a gap in the literature by developing a theory that bridges lesson study and self-efficacy. Since self-efficacy has been linked to student achievement, the theory is important as an explanatory mechanism linking lesson study to student achievement. The theory was developed using grounded theory based on primary source data primarily from planning and debriefing meetings. The theory demonstrates that lesson study is linked to self efficacy through a content continuum which implies that issues from pedagogical content knowledge to deeper conceptual matters can be addressed. It also implies that constraints arising in lesson study are most frequently limitations of pedagogical content knowledge which can be mitigated by a community of practice that provides appropriate resources and subject expertise.

Development of a Geometric Spatial Visualization Tool

Bibi Ganesh, Jennifer Wilhelm, Sonya Sherrod

This paper documents the development of the Geometric Spatial Assessment. We detail the development of this instrument which was designed to identify middle school students' strategies and advancement in understanding of four geometric concept domains (geometric spatial visualization, spatial projection, cardinal directions, and periodic patterns) after experiencing a carefully designed integrated lunar unit. Previous research with students using this lunar unit showed students making significant gains on lunar-related concepts (both scientific and mathematical) on a Lunar Phases Concept Inventory (LPCI) (Lindell & Olsen, 2002). Following the administration of single domain assessments, clinical interviews were conducted to ascertain students' problem solving strategies. Results allowed us to select four suitable multiple-choice items per domain.

Science Teacher Efficacy and Outcome Expectancy as Predictors of Students' End-of-Instruction (EOI) Biology I Test Scores

Christine Moseley, Julie Angle

The purpose of this study was to compare teacher efficacy beliefs of secondary Biology I teachers whose students' mean scores on the statewide End-of-Instruction (EOI) Biology I test met or exceeded the state academic proficiency level (Proficient Group) to teacher efficacy beliefs of secondary Biology I teachers whose students' mean scores on the EOI Biology I test fell below the state academic proficiency level (Non-proficient Group). The mean difference on the Personal Science Teaching Efficacy (PSTE) subscale scores between the two groups was not statistically significant. This indicates that personal science teaching efficacy was not statistically related to how a teacher's students scored on the EOI Biology I test.

The mean difference on the Science Teaching Outcome Expectancy (STOE) subscale scores demonstrated a statistically significant difference between the science teaching outcome expectancy of the Non-proficient Group and Proficient Group teachers. Proficient Group teachers had significantly higher STOE scores than teachers Non-proficient Group teachers. This finding suggests that End-of-Instruction Biology I test scores were related to the expectations that a teacher held for his/her students to learn biology regardless of student home environment, availability of classroom materials, or student motivation.

Research in the Classroom

The Flow Lab: A Simple Activity for Generating NOS Principles

Daniel Z. Meyer, Leanne M. Avery

While there is near universal agreement within the science education community that a strong understanding of nature of science (NOS) – both as a student goal and a teacher attribute - is critical, we still struggle with how to achieve these aims. Barriers range from pragmatic logistics to fundamental curricular tensions. In this paper, we share a classroom activity designed to aid in the learning of key NOS principles that we have found constructive. We discuss the basic activity, connections to science studies literature, and opportunities for explicit reflection on nature of science.

The Frequency, Variation, and Function of Graphical Representations within Standardized State Science Tests

Yi-Fen Y. Yeh
Erin M. McTigue
Texas A&M University

The purpose of this study was to determine the extent that diagrammatic literacy is necessary for success on standardized science tests at the late-elementary and middle grade levels. Towards this goal, we quantified the frequency, form and function of graphical representations on select state science tests. 985 tests items from 14 states were analyzed with 52.7% of the test items including graphical representations. The majority of these graphics, 79.5%, contained information that was essential for correctly answering the questions. The paper also discussed the trends of graphical representations in grade levels and alignment to national standards, following with teacher-implications.

Within the realm of high-stakes assessment of science achievement, one aspect of knowledge that is implicitly tested is the students' science communication skills, both verbal and visual. Thus, in order to be successful on such assessments, students need to both accurately interpret the task demands of the test and effectively convey their scientific knowledge. We propose that *diagrammatic literacy* (the ability to interpret and produce graphical representations) (Stern, Aprea, & Ebner, 2003) is a unique skill required for success on such assessments. The situation is analogous to how an essay-formatted test requires a successful test taker to be proficient in both writing skills and the domain knowledge of the essay topic; likewise, a science test which uses graphical representations indirectly tests diagrammatic literacy as well as science knowledge.

The purpose of this study is to examine what aspects of graphical knowledge students need to navigate standardized state science tests at the late elementary and middle school levels. Specifically, this study considers the types of graphical representations with which students need to be familiar and also the processes required to interpret the graphics.

Diagrammatic Literacy

In the following sections, we first review current findings regarding the overall teaching of communication of science with a recent shift towards more visual forms of expression. Next, we present the current graphical learning goals as outlined by national standards. Third, we present evidence as to why younger learners may respond differently to graphical representations than adults do. Finally, we briefly review research regarding the standards of state tests and rationale for test formatting choices.

Science Communication

Teaching science communication. Whether explicit or implicit in the curriculum, the teaching of science means also teaching the communication of science: written, oral, or visual (Cobb et al., 2004). Unfortunately, explicit teaching of the communicative aspects of science (i.e., science literacy) is often overlooked in science education in favor of covering more content (Osborne, 2002). Additionally, within the realm of overall communication taught in schools, visual literacy has consistently maintained a distant secondary role relative to verbal communication. Winn (1987, 1994) termed this phenomenon in schools a *verbal bias* and warned that this neglect could result in students under-developing the mental structures endemic to visual processing and undervalue this form. As a result, students may disregard much of the available information in graphics, rather than exploiting them to their full potential (Schnotz, Picard, & Hron, 1993) which may account for the rather "disappointing" (Peeck, 1993, p. 227) effects of pictures in educational settings.

The rationale for graphics in science communication. Graphical representations, particularly diagrams, have a coveted role in communicating knowledge from scientists to novices because their visual capacity allows the presentation of abstract concepts with concrete depictions. For example, the scale of science is often too large (e.g., continental drift) or too small (e.g., bacteria) to observe in a classroom, and teachers, authors, and test-designers must rely on visual depictions of the target. Diagrams and graphs are

also suitable to eliminate minor variations in order to consider the "big picture," such as looking at temperature change over time (Stern et al., 2003).

The visual shift. In addition to the unique role of graphics in science, traditional communication and literacy skills in schools are shifting in order to accommodate the increased use of digital formats (Leu, Kinzer, Coiro, & Cammack, 2004), and this shift has provided "optimal conditions for graphs and diagrams to be used as tool for presenting information, reasoning, and transfer" (Stern et al., 2003, p. 192). Due in part to technological progress in printing and visual software (Stern et al.), even the standard science textbook represents a showcase of complex diagrams and multimodal presentations with both the frequency and variety of these visual representations increasing markedly in the past decade (Martins, 2002; Moss, 2001; Walpole, 1999). On average there are 1.38 graphics per page in a high school science texts and 1.46 in science journals (Bowen & Roth, 2002) which represents a sharp contrast with literature texts.

Diagrammatic Learning and Teaching in Science

Diagrammatic learning goals. As a response to the unique role of graphical communication in science, experts of science education have put forth goals for diagrammatic learning. *The American Association for the Advancement of Science* (AAAS) in its *Project 2061* and its companion report, *Benchmarks for Science Literacy* (AAAS, 1993) outlined learning goals by grade levels. This report has influenced many U.S. state standards and subsequent science tests (AAAS). Of topical interest to this research study, are the benchmark performance standards for visual communication in science.

At the lowest grade levels, kindergarten through grade 2, the stated goals include students being able to create a drawing of a target object and/or concept and correctly represent its salient features. By the end of fifth grade, students are expected to be able to create sketches that explain either ideas or procedures. Additionally, they are to make use of numerical data to describe and/or compare objects or events.

By the end of middle school (eighth grade), students are expected to be proficient in both the interpretation and production of simple tables and graphs. This proficiency includes identifying relationships; verbally describing what tables and graphs indicate; and comprehending text materials that contain a variety of visual representations.

Young Learners and Graphical Understanding

Conventions of diagrams. Diagrams possess the potential to confuse students and inhibit comprehension, particularly among stylized graphics that reduce complexity and realism in favor of simplicity (Wheeler & Hill, 1990). Children are typically unfamiliar with the conventions of scientific diagrams. For example, the humble arrow, which seems so obvious at first glance, can represent six distinct functions in diagrams (Henderson, 1999) including the labeling of parts, noting a sequence of events, or demonstrating force but not directionality (e.g., in physics).

Integration of information. An additional challenge for the successful interpretation of graphics is that children often view an illustration as a discrete item, while adults are more likely to consider it within the textual context and to exhibit integration behaviors such as reading captions (van Parreren, 1983). As measured by eye-movement data, only the most skilled 4th and 5th grade students demonstrated integrative reading behaviors between the text and diagrams (Hannus & Hyona, 1999). In summary, the cognitive development of the learner (e.g., attention span), lack of previous experiences with instructional graphics, and the overall difficulty of the task may limit the utility of graphic support for young learners.

Characteristics of State Science Standardized Tests

In the final section, we consider characteristics of the state science texts that are relevant to this study. We briefly review the extent to which the standards of state tests have been developed consistently to each other and to national assessment scales. Additionally, we consider how the format of the standardized tests influences the test takers.

The standards of state tests. The standards and formats of state tests are determined not only by state curriculum but also by regional accreditation association and state educational policy. This results in multiple inter-state differences including in assessment frameworks, test specifications, psychometric properties and interpretations of AYP (Adequate Yearly Progress) (National Center for Education Statistics [NCES], 2007). Because of such discrepancies among state assessments, the National Assessment of Educational Progress (NAEP) performs as a means to more equivalently compare students' achievements and test standards between states. However, to better prepare students for this national level assessment, many states make alignments on their state assessments.

The formats of standardized tests. One area of relative consistency across standardized science test is in

Table 1
Types, Number of Test Items, and Year of Released State Tests

	Late elementary schools		Middle schools		
State	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8
CA		F. (45) 2007			S.(15) 2007
CO		S. (11) 2005			F.(30) 2004
FL		S. (15) 2008			F.(45) 2007 S.(25) 2008
IN		S.(12) 06		S.(17) 2005 S.(16) 2006	
ME	S.(18) 2006 S.(21) 2007				S.(19)2007
MA		F.(43) 2007			F.(43) 2007 F.(48) 2003
MT	S.(10) 2007				S.(11) 2007
NY	F.(44) 2006 F.(42) 2007				F.(80) 2007
OH		F.(44) 2007			
PA	S.(11) 2005 S.(18) 2007				S.(19) 2007
TN	S.(14) 2005	S.(14) 2005	S.(12) 2005		
TX		F.(40) 2004 F.(40) 2006			F.(50) 2006
VA		F.(40) 2006			F.(50) 2008
WV	S.(11) 2005	S.(11) 2005	S.(11) 2005		
Subtotal	S.(103)/F.(86)	S.(63)/F.(252)	S. (23)	S. (33)	S.(79)/F.(346)
Total	189	315	23	33	425

Note. F. represents that the full test is available and S. is for sample tests. The number in parenthesis is the number of items sampled (each sub-question was coded as a distinct item, in the instance of multiple sub-questions in one item). The year is listed next.

the type of answer format. These standard assessments are dominated by multiple choice questions, include limited free response/short essay questions and rarely to never evoke graphical representations. These formats frequently evoke criticism. According to Frederiksen (1984), multiple-choice tests are believed to assess factual recall and cover a broader range of topics, while free response/essay tests are believed to better examine students' organizational skills, inferential and in-depth thinking ability, and knowledge. However, this division may be too simplistic.

Thissen, Wainer, and Wang (1994) argue that either format can be used to assess the same proficiency and skills; in fact, only the contexts and testing goals affect the utilization of multiple choice and free response in test development. From a practical standpoint, free-response formats consume more time to score than multiple-choice formats, require trained scorers, and contain higher risk for subjectivity and unreliability (Tan, Imbos, & Does, 1994). While little research has examined the infrequent use of student-produced visual answers (e.g., draw a diagram to demonstrate the water cycle), these would be likely endowed with the same risks of free verbal response.

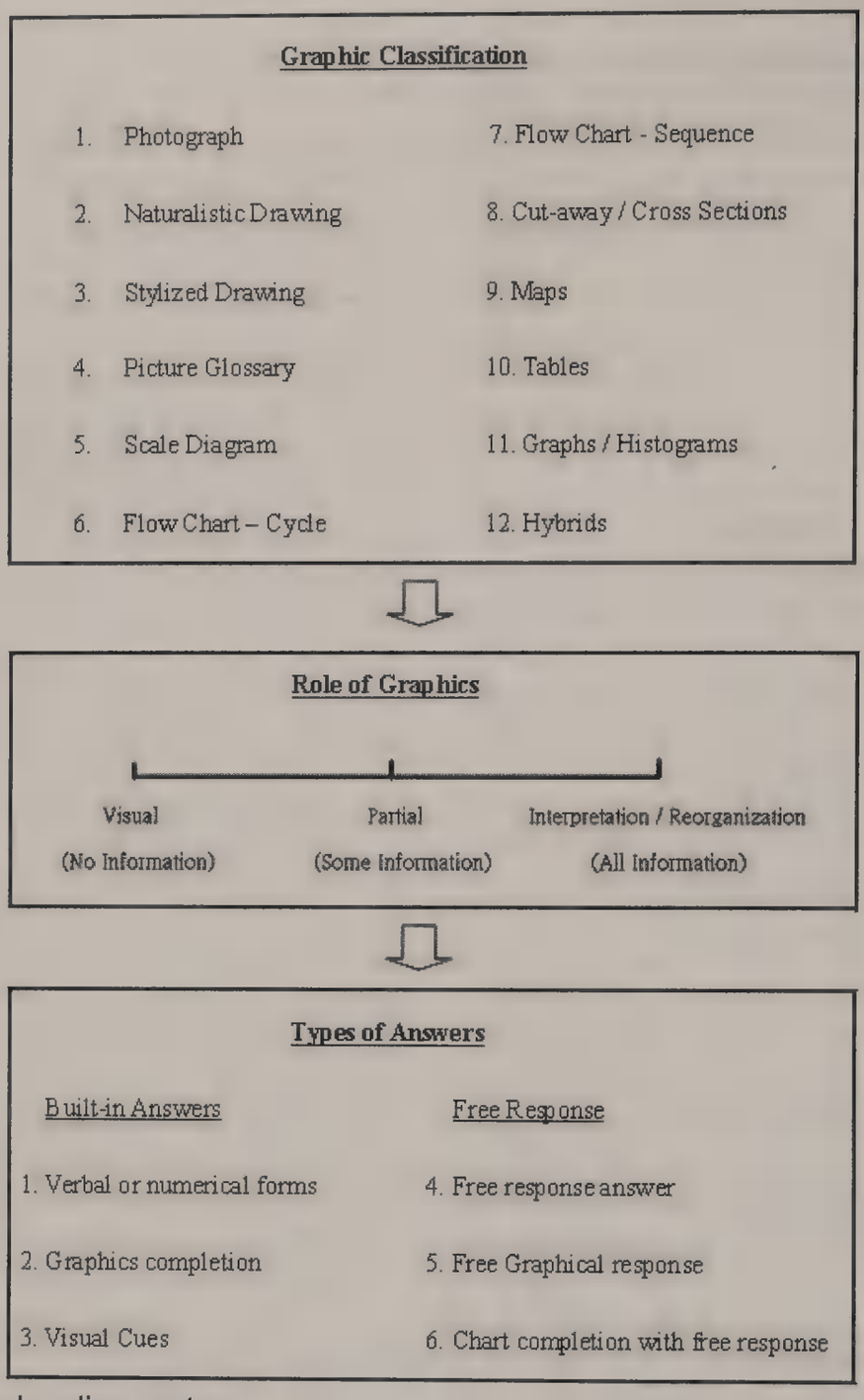


Figure 1. Three-tiered coding system.

Research Questions

In summary, we recognize a shift in the type of communication demands for science literacy with an emphasis on students needing to be diagrammatical literate.

Our research questions were:

1. What percentage of overall test items from state science tests included graphical representations?
2. What types of graphical representations were most common in state science tests?
3. Were there grade level trends regarding the relative frequency of graphical representations?
4. What was the functional role of the graphical representations within test items?
5. Were there grade level trends regarding the function of graphical representations?
6. To what extent did the role of the graphic depend on the type of graphic?
7. What answer formats were most frequently used on the standardized science tests?
8. Were there grade level trends regarding the answer formats within test items?

Methods

Sample

In this study we analyzed the graphical representa-

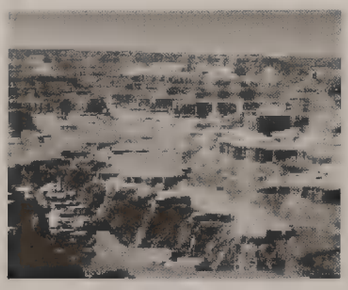
Table 2
Graphic Classification

Type	Definition
Pictorial Illustrations	(see Figure 2)
Photograph	The photograph of a subject or scenery is employed, e.g., the photograph of a glacier.
Naturalistic Drawing	All the features of the subject are depicted in detail, e.g., a bird covered with fine feathers.
Stylized Drawing	Graphics are delineated only with the outlines or in a symbolic drawing, e.g., an arm-chair.
Picture Glossary	Parts of the pictures are named with labels, e.g. a growing plant whose root and stem are labeled.
Charts & Graphs	(see Figure 3)
Scale	A scale is displayed beside the subject for indicating its size, temperature, distance, etc., e.g., a whale with a scale marked off in units of meters.
Flow Chart	Arrows or numbers are marked among stages, e.g., life cycle.
Map	Geographic features, like mountains or buildings, are marked to show spatial relation to others, e.g., a U.S. map noted with air flows.
Table	Tables are composed of cells, which are the products of rows and columns, e.g., a train timetable.
Graph / Histogram	Quantity information is recomposed in the format of relative graphs, e.g., histograms or pie charts.
Cutaway Exhibitions	(see Figure 4)
Cutaway Exhibitions	Internal parts or processes are marked with labels, e.g. the cross section of blood veins, where blood cells and platelets are labeled.
Hybrids	(see Figure 5)
Hybrids	Two or more graphics mentioned above are involved.

tions used within standardized state level science tests in the years 2003 through 2007. We sampled items from all available, officially-released, state-level science tests intended for late elementary and middle grade students, grades four to eight. Depending on availability, the test items were collected from both released *full tests* and from *sample tests,* meaning that only a limited number of items were released (this distinction is documented in Table 1). The final sample is composed of test items from 14 states: 1) California, 2) Colorado, 3) Florida, 4) Indiana, 5) Maine, 6) Massachusetts, 7) Montana, 8) New York, 9) Ohio, 10) Pennsylvania, 11) Tennessee, 12) Texas, 13) Virginia, and 14) West Virginia.

The majority of states in the sample administer a science assessment at the end of elementary school (in fourth or fifth grade) and middle school/junior high (eighth grade), as shown in Table 1. Consistent with states' choices of grade levels for testing and for ease in reporting, we grouped our results in two categories: late elementary tests (4th and 5th grades) and middle school tests (6th, 7th, and 8th grades). There were 504 test items from late elementary schools and 481 test items from middle schools.

Photograph

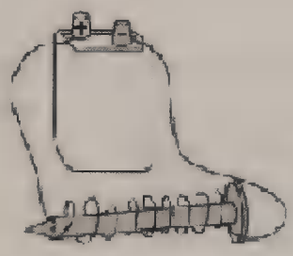


Note. From test item 19 in Grade 8 of 2007 Florida Comprehensive Assessment Test.

Naturalistic Drawing

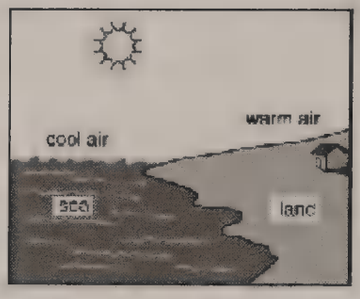
Note. From test item 13 in Grade 5 of 2008 Florida Comprehensive Assessment Test.

Stylized Drawing



Note. From test item 9 in Grade 5 of 2007 California Standard Test.

Picture Glossary



Note. From test item 30 in Grade 5 of 2007 California Standard Test.

Figure 2. Graphic classification – pictorial illustrations.

Procedures

We created a three-tiered system to code the collected test items regarding the classifications and roles of graphics, as well as the types of answers (see Figure 1).

The classifications of graphics

First, we classified all graphics in the tests and simultaneously coded whether the graphic was contained in the posed question or in the answer options. The coding system was based primarily on Moline's (1995) categorization system designed for teaching graphics, but modified during the development phase to better meet the needs of this study and prevent ambiguity in coding. Table 2 details the classification system used.

There were 12 specific graphical types that were distributed among four main categories of: 1) pictorial illustrations, 2) charts & graphs, 3) cutaway exhibitions, and 4) hybrids. Pictorial illustrations included the individual categories of a) photograph, b) naturalistic drawing, c) stylized drawing, and d) picture glossary. Charts & graphs included a) scale diagrams, b) flow charts, c) maps, d) tables, and e) graphs & histograms. Cutaway exhibitions came in two forms a) cutaways and b) cross sections. Hybrids were graphical representations that merged elements of multiple graphics, such as an enhanced photograph with labels and a key superimposed on the base image.

The Roles of Graphics

At the second tier, the *function* of the graphics to the test taker was analyzed to determine the level of information provided by the graphic and potential support to the test taker. We created a three-leveled scale, as displayed shown in Figure 1.

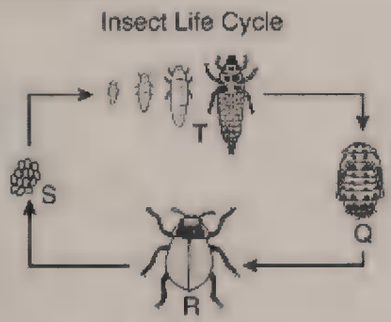
Level one. At the lowest level (level one), graphics functioned as simple concrete representations of verbal descriptions and displayed redundant information from the questions themselves. Such graphics were deemed *unnecessary* for answering the question because, without the graphical support, the question could still be answered correctly. For example, in Figure 6, the pictorial representations of the animals simply may clarify what a raccoon looks like, but does not provide additional information for completing the task.

Level two. At the next level (level two), the graphics provided partial information that was necessary, but not sufficient, for answering the question. That is, the test takers needed to derive information from the visual representations, the verbal question, and their prior knowledge in order to complete the task. In Figure 7 for example, the test takers had to both decode the ver-

Scale Diagram

Note. From test item 44 in Grade 5 of 2007 California Standard Test.

Flow Charts



Note. From test item 1 in Grade 5 of 2006 Texas Assessment of Knowledge and Skills

Maps

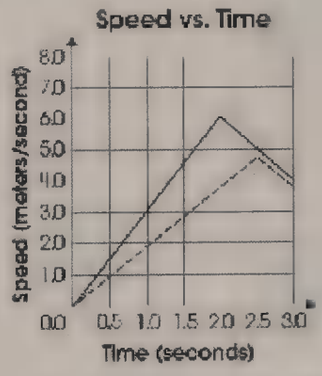
Note. From test item 44 in Grade 8 of 2007 Florida Comprehensive Assessment Test.

Tables

Speed and Distance Data for Car 1 and Car 2				
	Car 1		Car 2	
Time (seconds)	Speed (meters/ second)	Total Distance Traveled (meters)	Speed (meters/ second)	Total Distance Traveled (meters)
0.0	0.0	0.00	0.0	0.00
0.5	1.5	0.38	1.0	0.25
1.0	3.0	1.50	1.9	0.96
1.5	4.5	3.38	2.9	2.16
2.0	6.0	6.00	3.8	3.84
2.5	5.0	8.75	4.8	6.00
3.0	4.0	11.00	3.8	8.16

Note. From test items 31-34 in Grade 8 of 2007 Ohio Achievement Tests.

Graphs / Histograms



Note. From test items 31-34 in Grade 8 of 2007 Ohio Achievement Tests.

Figure 3. Graphic classification – charts and graphs.

bal questions and extract information from the flowchart cycle in order to comprehend the question. Then the test takers had to apply their background knowledge about plant growth to select the appropriate answer.

Level three. At level three, the graphics contained all the information that the test taker needed for answering the question. The test takers were required to *interpret* and typically *reorganize* the information in order to answer the question. However, they did not rely on facts from their background knowledge to answer the questions, but instead needed procedural knowledge. Referring to the example in Figure 8, if the student knew the procedure for reading a contour map, and could do the mathematical calculation, they could answer the question correctly. They would not need semantic knowledge about the height of a certain mountain.

Formats of Test Answers

On the third tier of analysis, we analyzed the format of the test answers. The seven individual formats were

Cutaway / Cross Sections

Note. From test items 15-18 in Grade 8 of 2006 Texas Assessment of Knowledge and Skills.

Figure 4. Graphic classification – cutaway exhibitions.

Hybrids

Rock Samples

Sample	Observations	Sketch
Limestone	• tiny grains arranged in layers • feels gritty • reddish tan or gray • has a fish fossil	
Conglomerate	• small rocks and pebbles of different colors stuck together • feels lumpy	
Obsidian	• looks like black glass • cannot see parts of other things • feels smooth	
Pumice	• light gray • has tiny holes like a sponge • very lightweight • feels very rough	
Granite	• tiny specks that are black, white and gray • specks are about the same size • feels rough	

Note. From test items 41-44 in Grade 5 of 2007 Ohio Achievement Tests.

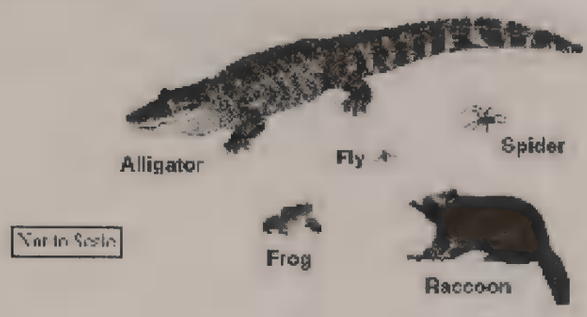
Figure 5. Graphic classification – hybrids.

divided into three major groups: built-in answers, free responses, and hybrids. Built-in answers referred to the test items with choice answers embedded either in the posed question or answer options, including 1) verbal or numerical forms (with multiple choices), 2) graphics completion (e.g., complete the third stage of a graphically depicted four-part life cycle), and 3) visual cues (e.g., select the correct graphical object). Free-response questions had open-ended formats, including 1) free verbal/numerical response (e.g., explain how to design an experiment), 2) free graphical response (e.g., draw a cross section of the Earth), and 3) chart completion with free verbal response (e.g., fill in the table of a growth record). Hybrids answer formats referred to a combination of two or more of the previously cited answers.

Data Analysis

Test items were coded in three separate sessions. The

The animals shown below live in the swampy, wooded areas of Florida.

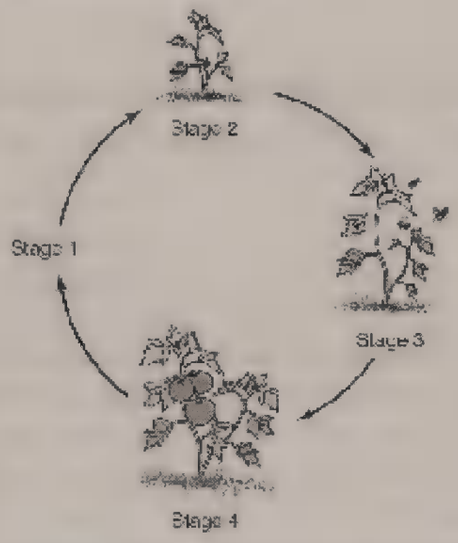


How would the animals shown above be connected in a food web? Explain your answer using words or a labeled diagram.

Note. From test item 4 in Grade 5 sample test of 2007 Florida Comprehensive Assessment Test.

Figure 6. The exemplar test item of graphical representation providing visual information.

Study the diagram of the life cycle of a tomato plant shown below. Two of the stages in the diagram are incomplete.



Describe ONE important thing that is missing from Stage 1 in the diagram.

_____

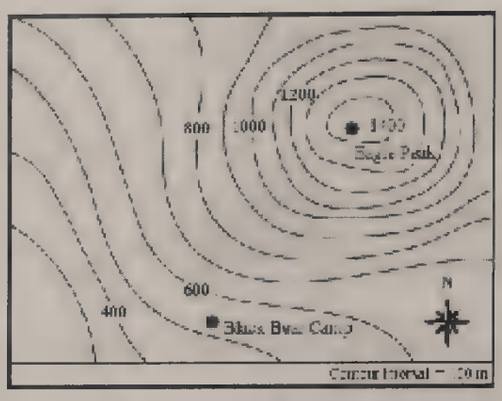
Note. From test item 5 in Grade 5 of 2006 Indiana Statewide Testing for Education Progress.

Figure 7. The exemplar test item of graphical representation providing partial information.

two coders were experienced teachers with advanced degrees in education. Initially, the researchers practiced with released items from tests prior to 2003 with an inter-rater agreement of 90.6 %. After three sets of iterations of the coding scheme, each of two researchers coded half of the test items a second time to verify the reliability of the system on the sample which resulted in 97.5 % inter-rater reliability. After final agreement on all test items was reached, the data was entered into SPSS and checked.

As this is a descriptive study to document the types of graphics, we report frequency and percentiles. To further delve into this sample by considering comparisons of grade level, we employed Chi-Square to determine if the differences in frequency between groups were statistically significant. It must be noted that due to availability of released state data, it is not possible to infer generalizations to all state science tests. This did not represent a random sampling of the U.S. state science tests although there was representation from every

A map with contour lines is shown below.



Which of the following is the best estimate of the difference in elevation between Black Bear Camp and Eagle Peak?

A. 400 m
B. 900 m
C. 1200 m
D. 1500 m

Note. From test item 36 from Grade 8 of 2007 Massachusetts Comprehensive Assessment System.

Figure 8. The exemplar test item of graphical representation providing partial information.

geographic region in the U.S.

Results

The study analyzed 985 test items from 14 state science tests in which 504 questions (51.2%) were from late elementary school tests, and 481 questions (48.8%) from middle school tests. 301 (30.6%) test items were collected from sample tests, and 684 (69.4%) items from full tests (see Table 1). The number of analyzed items was dependent on the number of released tests and items. The percentage of collected test items were ranked in the order of New York (16.9%), Massachusetts (13.6%), Texas (13.2%), Virginia (9.1%), Florida (7.6%), California (6.1%), Maine (5.9%), Pennsylvania (4.9%), Indiana (4.6%), Ohio (4.5%), Colorado (4.2%), Tennessee (4.1%), West Virginia (3.4%) and Montana (2.1%).

The Percentage of the Test Items Included Graphical Representations

The data revealed that 519 (52.7%) of the 985 released test items were accompanied by graphics, included in either the posed question, the answer, or in both sources. In terms of grade levels, 278 items (53.6%) from the late elementary school tests and 241 items (46.4%) from the middle school tests contained graphical representations.

The Most Common Types of Graphical Representations

Overall, the group of *pictorial illustrations* was the most frequently used (46.3%) and *charts & graphs* was the second (38.3%), followed by *hybrids* (12.9%) and *cutaway* exhibitions (2.5%). If we look from subcategories specifically, *stylized drawings* were the most prevalent graphical category, which accounted for 29.5% of total graphical representations. *Tables* at 14.8%, and *hybrids* at 12.9 %, represented the second and third most common graphical category respectively (see Table 3).

Grade Level Trends. On the late elementary tests, the frequency of pictorial type illustrations (54%) was higher than charts & graphs (33.4%). Hybrids (10.1%) were ranked as the third and cutaway exhibition (2.5%) were the least common types. In contrast, on the middle school tests, charts & graphs were the most frequent (44%) and pictorial type illustrations were the second most frequent (37.3%). Like in the late elementary school tests, hybrids (16.2%) were ranked as the third most common type and cutaway exhibitions (2.5%) were the least common, as shown in Table 3 and Table 4.

Table 4 also provided actual frequencies with (expected frequencies) of graphical representations by

Table 3
Frequencies and Percentage of Graphic Types by Grade Levels

	Late elementary		Middle school		All	
Graphic category	Freq.	% within the grade	Freq.	% within the grade	Freq.	% within the grade
Pictorial illunstrations						
Photograph	4	1.4%	3	1.2%	7	1.4%
Naturalistic Drawing	27	9.8%	5	2.1%	32	6.1%
Stylized Drawing	90	32.4%	63	26.1%	153	29.5%
Picture Glossary	29	10.4%	19	7.9%	48	9.2%
Charts & graphs						
Scale diagram	14	5.1%	10	4.2%	24	4.6%
Flow chart	27	9.7%	19	7.9%	46	8.9%
Maps	4	1.4%	16	6.6%	20	3.9%
Tables	41	14.7%	33	13.7%	74	14.3%
Graphs/histograms	7	2.5%	28	11.6%	35	6.7%
Cutaway exhibitions	7	2.5%	6	2.5%	13	2.5%
Hybrids	28	10.1%	39	16.2%	67	12.9%
Total	278	53.6%	241	46.4%	519	100%

Table 4
Observed Frequencies and (Expected Frequencies) of Graphic Groups by Grade Levels

	Pictorial illustrations	Charts & graphs	Cutaway exhibitions	Hybrids
Late elementary	150 (128.6)	93 (106.6)	7 (7.0)	28 (35.9)
Middle school	90 (111.4)	106 (92.4)	6 (6.0)	39 (31.1)

grade levels. The 2 (grade levels) 4 (graphic categories) chi-square test indicated that the frequency of graphic categories differed by grade levels, $.99\ (3) = 15.171$, $p < .01$ (i.e. Pictorial illustrations were the major group followed by charts & graphs in late elementary grade level while charts and graphs were followed by pictorial illustrations in middle school level).

Functional Roles of the Graphical Representation

In the overall sample, 54.7% of the graphics provided partial information to the test taker (i.e., Level 2). 28.5% of the graphics provided all necessary information for test-takers to interpret and reorganize the information (i.e., Level 3). Only 16.8% of the graphics provided no additional information but were visual representations of the information stated in the question (i.e., Level 1).

Grade Level Trends. There were no grade level differences in the relative frequency regarding the functional role of graphics.

The Dependence of Roles on the Graphical Types. To explore the role of graphics in relation to the graphical types, we considered both in concert. Of pictorial illustrations, 24.2% of them functioned as redundant visual representations (Level 1), 68.3% of them provided partial information (Level 2), and 7.5% of them provided all necessary information (Level 3). Of the charts & graphs, 11.6%, 37.7% and 50.8% were categorized as Levels 1, 2, and 3 respectively. For the cutaway exhibitions, 7.7%, 69.2%, and 23.1% were categorized as Levels, 1, 2, and 3 respectively as well. Finally, of the hybrids, 7.5%, 53.7%, and 38.8% were also categorized as Levels 1, 2, and 3 respectively.

The graphic types by the functional roles are summarized by actual frequencies with (expected

Table 5
Observed Frequencies and (Expected Frequencies) of Graphic Types by the Functions

	Pictorial illustrations	Charts & graphs	Cutaway exhibitions	Hybrids
Visual information	58 (40.2)	23 (33.4)	1 (2.2)	5 (11.2)
Partial information	164 (131.3)	75 (108.9)	9 (7.1)	36 (36.7)
All necessary information	18 (68.4)	101 (56.7)	3 (3.7)	26 (19.1)

frequencies) in Table 5. The 4 (pictorial illustrations, charts & graphs, cutaway exhibitions, and hybrids)3 (roles of graphics) test result indicated that graphic categories were not independent of their functions, .99 (6) = 108.653, $p < .01$. A notable finding is that the majority of pictorial illustrations carry partial information the most while the majority of charts & graphs carry all necessary information.

The Most Frequently-used Answer Formats

In terms of answer formats, the items with graphical representations were categorized into three major groups: 1) built-in answers at 76.3% (verbal/numerical forms at 49.5%, graphical completion at 3.3%, visual cues at 23.5%), 2) free response at 23.1% (free verbal/numerical response at 19.8%, graphical response at 2.3%, chart completion with free verbal response at 1%) and 3) hybrids at 0.6%.

Grade Level Trends. At the elementary level, 84.5% were accompanied in built-in answers and 15.1% were in free response. As for the middle school level, the percentage of built-in answers was 66.8% and the percentage of free response was relatively higher, at 32.4%.

Discussion

Within the following section we discuss 1) the importance of diagrammatic literacy for success on state science tests 2) the interrelations between graphical type and their function and 3) alignment of national standards and state science texts in reference to diagrammatic literacy. We conclude with implications for science teachers.

Importance of Diagrammatic Literacy

The accurate interpretation of graphical representations is critical for success on the state science tests surveyed. Not only were graphics used with great frequency throughout standardized science tests (accompanying 52.7% of questions), the graphics also possessed information that was critical for students to answer the questions. The majority of graphics, 79.5% at the late elementary schools and 87.6% at the middle schools, contained either partial, or all necessary information, for test takers to answer the questions.

The indispensability of diagrammatic literacy is validated through the observable high frequencies of graphical representations accompanying with critical information embedded with them. Furthermore, on a more global level, when one considers the increase in overall use of graphics in texts and online environments, the graphical demands on these tests, at least in terms of frequency, accurately reflect the current visual demands of reading science texts. However, the development of diagrammatic literacy for science may not naturally evolve from having mastery of the domain knowledge of science. In the same manner that learning to read and write science requires specific skills beyond hands-on science experiment, diagrammatic literacy requires an additional set of skills. Navigating the graphical information should be approached differently than navigating linear verbal texts. Consequently, helping students decode, navigate and ultimately produce graphics should be considered one major goal for science literacy enhancement.

The Genres of Graphics and Related Function

Graphical displays encompass many varieties of visual display which use "different conventions to communicate information" (Vekiri, 2002, p.264), making specific types better suited for certain functions. The findings of this analysis reveal patterns of graphic functions regarding the type of graphic.

Based on the results, charts & graphs were most likely to carry all the needed information and require tasks of reorganization and transformation to answer the questions. The findings are not surprising when one considers the fundamental construct of charts or diagrams and pictorial illustrations. Charts or tables condense information in an organizational manner. Hence, it is important for students to have procedural knowledge on how to use charts and graphs.

In contrast, pictorial illustrations were found to carry partial information most frequently and therefore require skills of integration with the textual information.

These illustrations, with limited verbal information, depict information that is more appropriate for the visual domain than the verbal, such as indicating relative location, size, shape, directionality, layers and hidden processes.

Due to the relationships between the type of graphical representation and their function, it is imperative that students reflect on the purpose and relative effectiveness of graphical representations. Analogous to how students' comprehension benefits from instruction on text structure when reading a science article (e.g., cause & effect versus compare/contrast) (Samuels, Tennyson, Mulcahy, Schermer, & Hajovy, 1988), it may be useful for students to understand graphical structures when encountering a new representation. Each type of graphical representation can be considered similar to a genre of text, and it may be useful for teachers to present *genres of graphical representations*. For example, although, there are unique aspects between specific charts and tables, there are functions and conventions that are endemic to *all* tables and can provide strategies for students encountering a new chart or table.

Alignment of Diagrammatic Literacy Requirements and Benchmarks

According to the standards set forth in Benchmarks (AAAS, 1993), students who have reached the fifth-grade level should be able to describe, in both verbal and graphical ways, a given procedure or idea. This would indicate that students should be able to produce graphical representations. However, this expectation was not directly tested by the assessments due to the predominance of multiple-choice questions. Multiple-choice formats generally require a one way transformation of knowledge – from visual to verbal, rather than requiring students to create a visual form. While it would be a difficult task to score student-produced graphical representations, such tasks would be the most valid measure of their ability to use them within science inquiry.

Upon completion of eighth grade, according to Benchmarks (AAAS, 1993), students should have developed the ability to analyze and interpret information presented to them in the form of tables, graphs, and diagrams. This goal was only partially reflected on the tests. On the middle school tests, charts & graphs and pictorial representations were almost equally represented (44% and 37.3% respectively) which indicates an expectation that the students be equipped to navigate at least two major groups of graphics, whereas the primary grades were dominated by pictorial representations. However, cutaways and cross sections, which are the most complex analytical diagrams (Moline, 1995), were only 2.5% of the middle school sample revealing that the included graphical representations were of the simpler variety.

In terms of the answer formats, while the middle schools had more test items requiring students to express their thoughts, the free-response formats asked for verbal or numerical responses but rarely asked for graphical or chart completions. The format of free response indicates expectation of higher order thinking and may increase the retention effects of concepts and skills (Gay, 1980), but again these formats did not stress visual elements.

Teacher Implications

The prevalence of graphics on state tests indicates that students are expected to be proficient in understanding how to interpret visual information. Consequently, helping our students decode and interpret graphics should be common in teaching the communication of science and embedded in authentic inquiry.

The interpretation and production of graphics is a reciprocal learning process – the ability to decipher complex or informational graphics is scaffolded and sharpened through continuous and diverse experiences dealing with them. Students will not learn to use graphics due to exposure to them but through using them as part of their scientific inquiry (Bowen & Roth, 2002) and reflecting on their use.

For example, students could construct tables to record experimental information from a hands-on experiment. Next, they can transform a table into a line graph and consider the merits and benefits of using a table versus a graph. Teachers can ask probing questions such as: Would you want to use a table or a chart if you wanted to demonstrate to your viewers the change in temperature over time? To take the analysis further, students could construct a line graph and a bar graph and consider which is more appropriate to present the current data. Through the process of using graphics in authentic inquiry *and* simultaneously analyzing their use, students will be equipped to interpret new visual presentations of information. In addition, the process of transforming information depends students' understanding of that information.

Ainsworth, Bibbym, and Wood (2002) observed the cognitive economy of a multi-representational system.

After students tackled significant amounts of complex problem solving tasks with multiple representations, they were likely to better recall the outcomes of the thinking process and reproduce it through a new representation. If students are only expected to interpret graphics without ever producing them, they will be limited in their understanding. Tests should reflect this bidirectional transformation of information from verbal to visual and vice-versa.

Limitations

First, the analysis of students' individual performance errors would be critical to understand if students struggle with certain types of presentations. Second, this study did not analyze graphical representations in terms of students' cognitive processing domain. This was an exploratory study and the categories of cognitive processing emerged throughout our classification procedures were not based on an existent hierarchy. A system, such as Bloom's taxonomy, could be used as pre-existing categories in order to sort the learning demands of this question. This study also did not consider the complexity of the graphical representations. From our qualitative observations, we noticed that the tests were dominated by simplistic black/white line drawings. These types of representations are not the same quality as those in the textbook. However, our coding system did not quantify the quality of the graphics or their visual characteristics. Finally, our categories were broad in nature and specifically the category of "hybrid" representations could be analyzed further to better understand the manner in which graphical types are often layered upon each other.

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The Relationship Between Lesson Study and Self-Efficacy

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This article addresses a gap in the literature by developing a theory that bridges lesson study and self-efficacy. Since self-efficacy has been linked to student achievement, the theory is important as an explanatory mechanism linking lesson study to student achievement. The theory was developed using grounded theory based on primary source data primarily from planning and debriefing meetings. The theory demonstrates that lesson study is linked to self efficacy through a content continuum which implies that issues from pedagogical content knowledge to deeper conceptual matters can be addressed. It also implies that constraints arising in lesson study are most frequently limitations of pedagogical content knowledge which can be mitigated by a community of practice that provides appropriate resources and subject expertise.

Lesson study is a form of action research (Taylor, Anderson, Meyer, Wagner, & West, 2005; Yoshida, 1999) that uses joint lesson planning combined with observation lessons to refine teacher understanding of details surrounding a particular lesson. The lesson study process has been described by many authors (Blum, Yocum, & Trent, 2005; Fernandez & Chokshi, 2002; Kelly, 2002; Rearden, Taylor, & Hopkins, 2005; Taylor et al.) and is briefly explained here for completeness.

Although the process of lesson study and its benefits have been described, the mechanisms through which lesson study contributes to improved instructional practice and increased student achievement are not well developed. This is unfortunate because a better understanding of the mechanism, as opposed to anecdotal evidence, could be the basis for policies facilitating self-regulatory professional development. In this article I will describe a qualitative investigation of three middle school teachers engaged in lesson study. The purpose of the article is to present a substantive theory of how lesson study contributes to reflective practice and teacher self-efficacy

Literature Review

Lesson Study Characteristics

The group establishes a curriculum based focus for the lesson study that serves to define observable elements in the classroom. They construct a detailed lesson plan that includes a list of anticipated student responses (Fernandez, Cannon, & Chokshi, 2003; Meyer, 2005; Yoshida, 1999). A teacher implements the lesson while the other teachers observe the classroom. The observing teachers focus on concrete observations pertaining to the focal objectives and keep notes for later discussion. The group meeting, which follows a protocol (Chokshi & Fernandez, 2004), provides a forum for discussion of the lesson and observations. Modifications to the lesson are planned and a second teacher teaches the modified lesson while being observed in the same manner as the first lesson. Subsequently, a second group meeting provides a forum to discuss differences that arose from the changes made to the lesson plan. Toward the end of the process, a written report summarizing the lesson plans, observations and teachers' reflections is produced. In some instances, an overall discussion rather than a written report has been suggested (Blum et al., 2005). Variations of lesson study arise because the method is one technique in a family that share classroom observation, collection of data and subsequent analysis (Lewis, Perry, & Murata, 2006).

Wagner (2003) succinctly articulates the promise of lesson study: "[lesson study] develops pedagogical content knowledge, it is situated and authentic, it involves discourse communities, and it promotes sustained and generative growth" (p. i). However, the actual mechanism by which lesson study causes change is not understood (Lewis et al., 2006). In particular, claims, such as Wagner's ignore the small sample sizes and the need for a causal link between specific changes and improvements in teaching.

Lesson study occurs within the same physical space as the teacher teaches (Yoshida, 1999). The discussion after each lesson can be quite specific to the circumstances of the school and the teachers who are participating in the lesson study. Teachers are motivated by "reflective immediacy" (Shulman, 2003), the way their discussions can immediately be used to adapt changes in classroom practices (Hartman, 2004).

Potential Benefits of Lesson Study

Within the teacher's context, lesson study provides

an opportunity to improve vertical alignment through collaboration (Meyer, 2005). Through a sharing of content knowledge (Watanabe, 2002) collaborating teachers recognize the content foci of other teachers and the relative strengths and weaknesses of students from other classes. Over time lesson study should slowly alleviate issues of discrepant content knowledge between classrooms.

Teachers reflect on teaching materials, the process of learning by children, and the method of developing a lesson plan (Yoshida, 1999). Discussions between teachers focus on the different types of solutions that students generate for math questions, which is consistent with increased levels of student centered learning (Kinzer, 2005). Discussion of student responses facilitates improvements in teachers' pedagogical content knowledge (Meyer, 2005) including student-centered changes through apprenticeship (Oshima et al., 2006).

Teachers develop improved collegiality (Taylor et al., 2005) and confidence (Rock & Wilson, 2005) through their participation in lesson study. These factors are correlated and a predictor of student achievement (Puchner & Taylor, 2006). Some authors have noted a significant increase in student engagement (Puchner & Taylor) including student collaboration (Meyer, 2005).

For teachers, lesson study planning has been observed to increase the sophistication of teacher's planning (Stewart & Brednefur, 2005). The lesson study planning should include the choice of problems, manipulatives, wordings, the expected learning process, a method for gauging learning and ties to the curriculum (Takahashi & Yoshida, 2004). Manipulatives include aspects of the classroom, such as the explicit use of the chalkboard (Yoshida, 1999).

Lesson study owes its success to many features. Flexibility to address different aspects of teaching, the authentic contextual nature and the capacity to address personal pedagogical and pedagogical content knowledge needs may all contribute to its success. In addition, collaboration, particularly the development of professional communication, deepens existing collegial relationships and shares expertise. The skill of planning lessons is improved and a collaborative leadership has an opportunity to increase the professionalism of their staff.

Methodology

Participants

The lesson study took place in an urban elementary school, in Ontario, with a mixed socio-economic composition. The school had approximately 700 students and standardized grade six scores in mathematics have been within 2% of the Ontario, Canada, provincial averages for the past three years. The teachers taught grades 6, 7, and 8 and believed that lesson study would provide an opportunity to examine vertical alignment in mathematics within their division. The three teachers had 5 to 10 years teaching experience with academic backgrounds in English and physical education. One teacher was involved in math leadership within the school.

Data Sources

Data collection included audio recordings of all lesson study meetings (6.8 hours), field notes, a brief individual survey about teaching background and individual semi-structured interviews reviewing interpretations of each teacher's activities, as well as artifacts that the teachers produced. The collected artifacts included lesson plans, classroom handouts and participant observation notes written on seating plans.

The particular format of the lesson study focused on vertical alignment around the topic of equation solving. The teachers did not feel it would be appropriate to teach the same lesson at three consecutive grade levels. They decided to plan lessons at each grade level that focused on the techniques that each teacher typically used. The discussion leading into each classroom observation led to an improved understanding of the grade level context. Through the planning, discussion and the debriefing a variety of options were discussed that would facilitate further adaptation and understanding of the teaching methods. The process provided a better understand of the flow of the curriculum and the distinct methods used by the three teachers for the three consecutive grade levels.

Analysis

Lesson study meetings were transcribed and analyzed using N6. An initial set of codes was developed by the researcher and an inter-rater reliability check was performed using text samples from early planning meetings. The reliability check served to clarify the researcher's initial interpretation of codes. This was then used by the researcher to develop a code book when transcription of all the meetings was completed. The final codebook was validated by two colleagues who agreed upon the intended meaning but suggested some minor wording changes.

The analysis used axial coding (Kelle, 2005) with reflective practice as the coding paradigm. Theoretical

codes (Strauss & Corbin, 1994) emerged and evolved as the data were explored. Particular attention was given to the existence of two simultaneously distinct contexts; the classroom that was observed and the lesson study meeting.

Using the finalized codebook, data were reassembled with the content organized into thematic vignettes. For example, algebra tiles were mentioned multiple times during different meetings and these mentions were extracted under different components of the codebook. The different extracted segments were brought together in chronological order. This facilitated member checking and the examination of pathways between constructs during the chronological progression of particular foci in the lesson study. Member checks acknowledged that the record was "very thorough", there were no omissions and only minor wording changes were suggested.

The finalized theoretical coding, combined with the vignettes, facilitated the emergence of processes sequentially linking multiple constructs. These processes represented underlying patterns and, as more vignettes were considered, repetitions of patterns providing support of multiple perspectives (Strauss & Corbin, 1994) were recognized.

Results

In this section I will present two vignettes that illustrate the substantive theory that developed from the study. The vignettes pertain to algebra tiles and a method called "other's mark". They are representative of the types of discussions that took place that were directly related to classroom instruction.

Vignette: Algebra Tiles

Algebra tiles arose during a discussion of curriculum alignment with respect to equation solving expectations. The grade six teacher inquired about tile use which led to a tutorial and her subsequent effort to implement them. The tutorial included a detailed demonstration, answers to several questions and practical comments regarding classroom use:

- What antecedent conditions would she need to set up?
- Who in the school had class sets of algebra tiles?
- There are tile sets for demonstrations using an overhead projector.
- Keeping the numbers in the equations relatively small because there are only so many tiles in a kit and students perceive equations with larger values as "a more abstract problem."
- The integer skills would exceed student ability but using the tiles as a visual indicator would make a full understanding of integer addition and subtraction unnecessary, provided the final answer was positive.

While the tutorial occurred at a lesson study meeting, the teacher had another shorter review when she picked up the algebra tiles kits. She later explained this visit as:

> Well that would be why I went to [participant who gave the algebra tiles tutorial] about the algebra tiles. It is exactly the same thing, I was like; Show me that one more time because I think I have it, but I am not one hundred percent sure.

The teacher used what she had learned about the algebra tiles to implement them in her classroom. The algebra tiles were used to introduce equation solving to her class in preparation for problem solving using equation solving.

After implementing algebra tiles the teacher reflected: "I don't think I would change it, I think I would use it more often, and think of other ways I could use algebra tiles." When asked if the conversation at the earlier meeting had put her at ease, she responded "Yes. Oh definitely. I never would have used them before." As for the future, she indicated "I'll go back again." Access to algebra tile kits in the school was crucial and resolved through the collaboration.

The lesson study use of algebra tiles started with an area of concern, 'How to improve equation solving?', and through peer support generated some suggestions. There were several iterations of providing pedagogical content knowledge and addressing pedagogical questions that emerged. The teacher learned enough that her self-efficacy increased sufficiently to implement algebra tiles. However, just prior to actually implementing the tiles, reflective self-perception caused her to consult her peer for a review of the pedagogical content knowledge. Since this went well, her self-efficacy was sufficient to implement the tiles. Post-implementation reflections showed that she maintained a high level of self-efficacy and is quite likely to use algebra tiles again. The explanation of this vignette, in terms of the theory, will be clarified following the presentation of the theory.

Vignette: "Other's Mark"

An instructional method referred to as "other's mark" was suggested by one teacher as a method that might be of interest to the other two teachers. It was described as pairing students who are at different levels

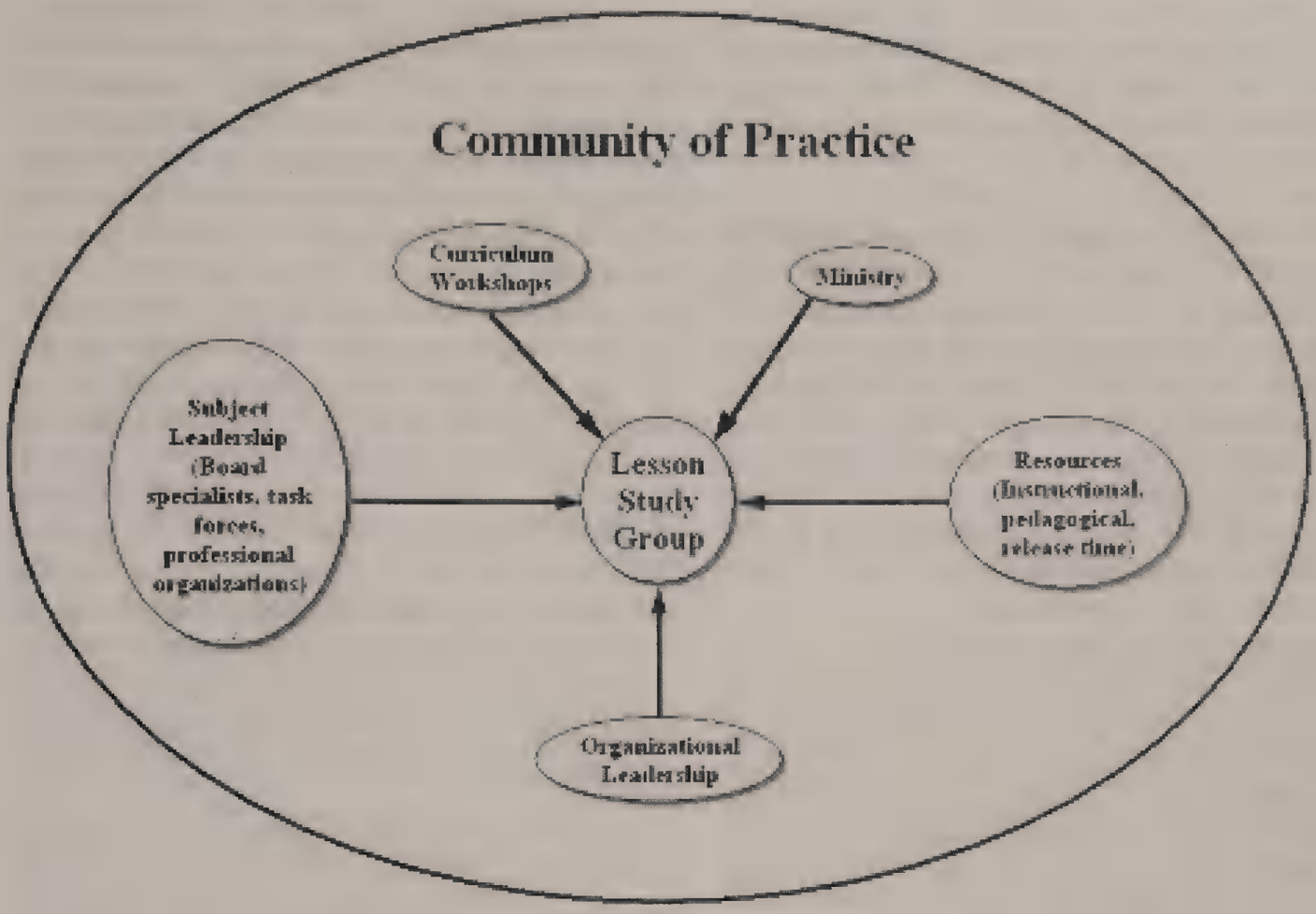

Figure 1. Community of practice.

of achievement in order to solve a problem. The students are told that the strong student will receive the mark of the weaker student, for the assigned problem, and the weaker student, the mark of the stronger student. This is a motivational ruse and not the basis of assessment, it was suggested that one might assess student engagement but the marks for solving the problem are not genuinely used to assess individuals' achievement. However, for students, the teacher's statements about the proposed switching of marks motivate the stronger student to ensure that the weaker student understands the solution to the problem well enough to achieve a good mark. The weaker student has more support, less stress and can therefore focus on learning the material.

The technique was described in response to a discussion between the teachers to resolve the distinction between 'communication' and 'group work'. It was also suggested that the strategy might help to reduce competition between students in the classroom. The teacher who described the technique contrasted it with Kagan strategies because the teachers had received in-service training regarding Kagan strategies. Both teachers who were unfamiliar with the technique were interested to see the method being applied. The teacher provided a demonstration of the technique in his classroom while the other two teachers observed.

At the debriefing session one teacher was very positive about the technique while the other was reserved. They both indicated that they were confident that they could implement the technique. However, one teacher indicated he would initially try implementing the method in language arts before trying to use it in his math class where his students are much more competitive. He wasn't against using the method in math but believed he was more likely to be successful with prior experience from his language arts class. The other teacher remained reserved because she had, as the lesson study group acknowledged, a "culture of collaboration" among the students of her class. She was concerned that the technique might interfere with the cooperation observed in her class.

The group spent some time discussing pairings of students. This was a notable feature of the vertical alignment lesson study; interpretations of specific behaviors of individual students could be compared by

the different teachers who had taught the student. While the details did not add to the other's mark technique, it did highlight the context specific considerations that the teachers' were considering with respect to implementing the method.

Substantive Theory

The theory is developed in three parts. Firstly, the community of practice is defined as an inclusive means of explaining the variety of resources the lesson study called upon. The second component is a model of math teaching that emerged and allowed the encapsulation of a full range of content and pedagogical elements from classroom enactment of particular pedagogical content knowledge through to philosophical views and principles of both teaching and mathematics. Finally, the third component uses the first two components to link lesson study to self-efficacy.

The community of practice (see Figure 1) was defined by considering sources of influence from the teacher's perspective. The most frequent influences were classroom based; resources, peers, other teachers of the same grade or division. Less frequently consulted influences were the organizational leadership of the school; lead teachers, and the principal. Board workshops with subject leadership and the Ministry of Education, particularly through curriculum documents, are key influences.

The pedagogical and curriculum aspects of the study varied greatly and the emergent theory had to facilitate discussions that could include varying degrees of abstraction, from concrete aspects of a classroom to systemic notions, along pedagogical and content lines. Distinguishing these two lines and allowing for a range of levels of abstraction required the emergent theory to have a particular structure. The emergent theory, hereafter referred to as a general model of math teaching (see Figure 2) has pedagogical components, or curriculum orientation, represented on the top sloped line and content components on the lower sloped line. Each line highlights different approaches to discussion that reflect the scope of statements that were made, these may be thought of as having different levels of abstraction with the most concrete appearing on the right and the most abstract on the left. The slope of the lines was included as a means to show the divergence of content and pedagogy when the scope of discussions was abstract and convergence toward PCK when discussions focused on concrete classroom features or observations.

The content orientation illustrates that math content is much larger than the content taught in schools and that there is an interaction between math content in schools and content in the larger math community. The vertical dashed lines highlight the typical affiliation of

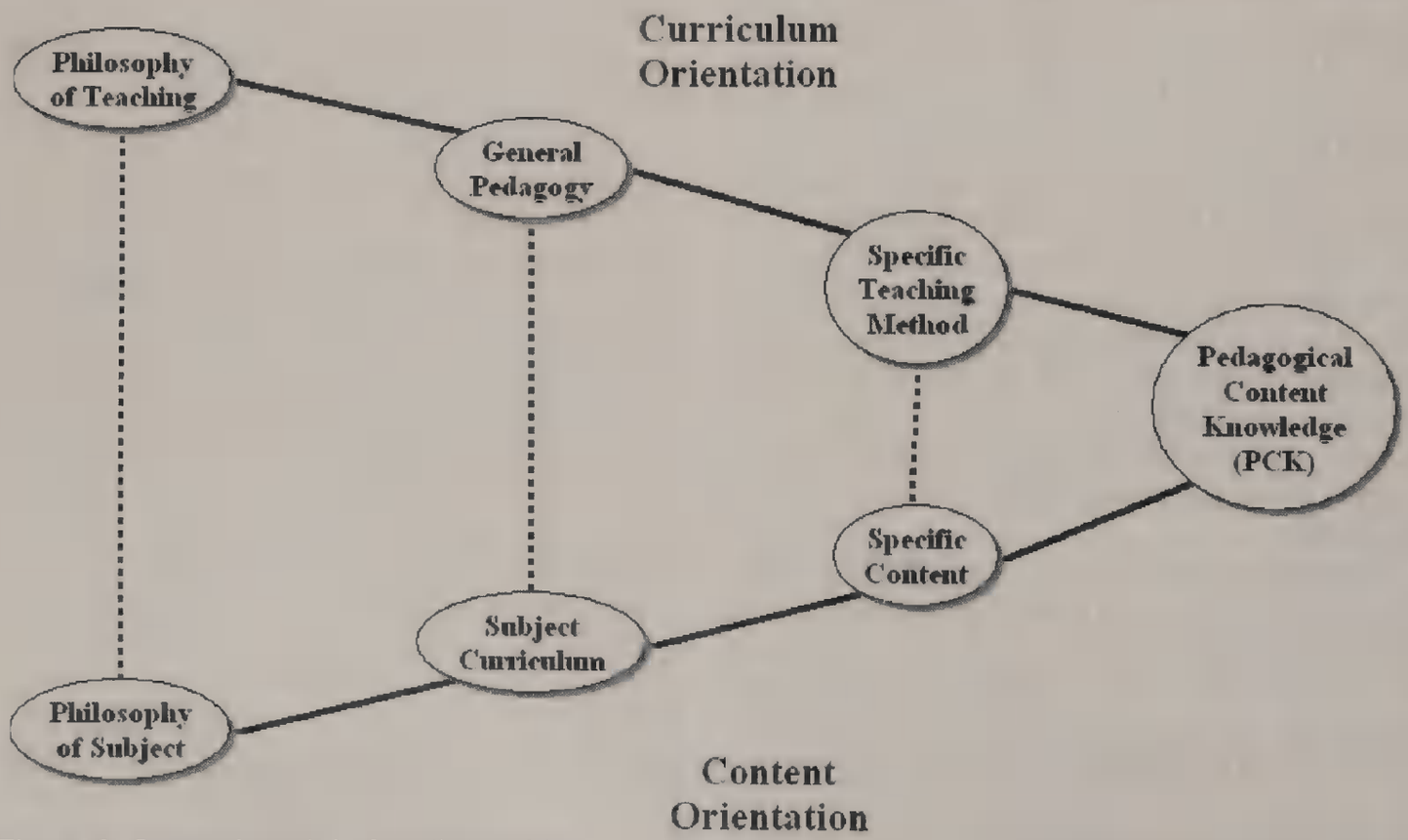

Figure 2. General model of math teaching.

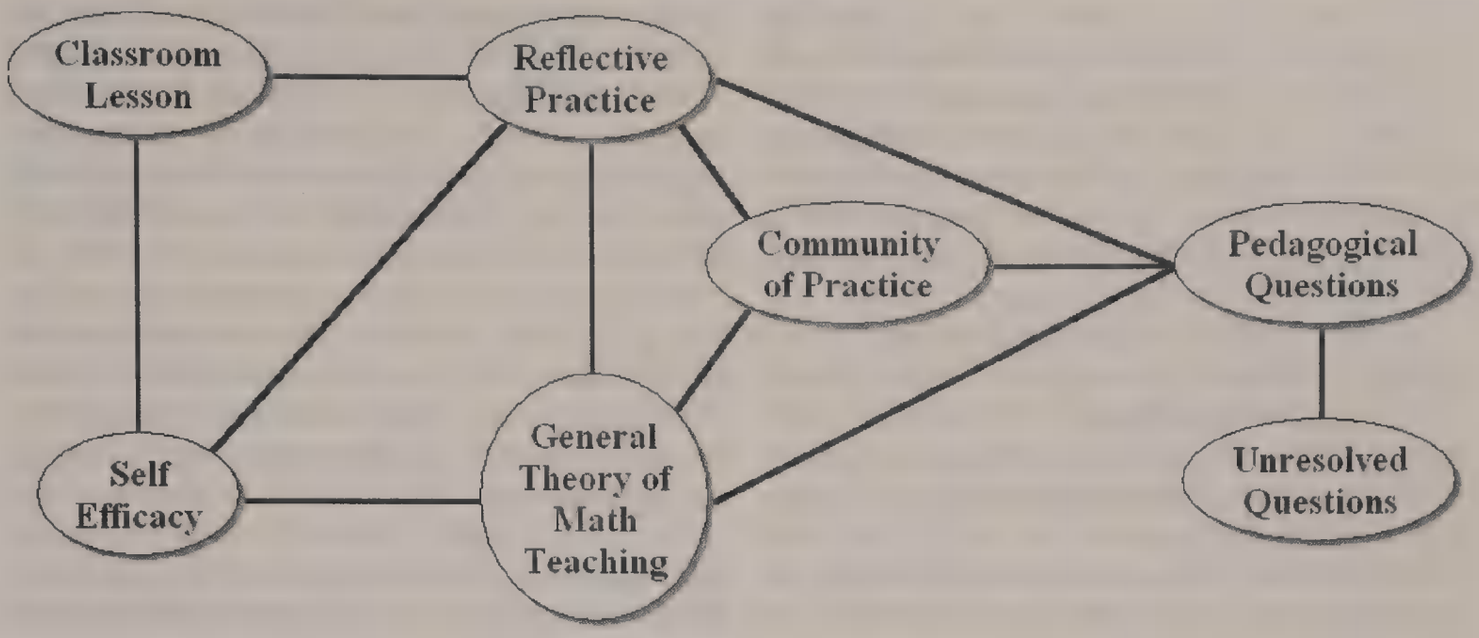

Figure 3. The substantive theory.

pedagogy with an equivalent level of content. At the right, the intersection of pedagogy and content is pedagogical content knowledge which combines specific content objectives with a particular instruction technique. The middle pair of circles relates general content, for example graphing, to standard expectations of practice, such as using graphing calculators.

The subject curriculum can be interpreted as a sequence of content items within the general content. The leftmost pair of circles represents an abstraction of foundational views from which the teacher's actions are derived. Philosophy of teaching represents a personalized context of deeply seated views of teaching and pedagogy in a general sense, while philosophy of content is a personalized context of deeply seated views specific to the content area.

The use of the community of practice and the general model of math teaching facilitated the construction of the theory providing linkages between reflective practice and self-efficacy (see Figure 3). To understand the theory, consider a circumstance where a teacher plans a lesson which effectively starts the process at the "general model of math teaching." For a given lesson the teacher pairs specific content objectives with appropriate pedagogical techniques. The teacher has a level of self-efficacy regarding the lesson which may be due to reflections on past usage (or lack of familiarity if they are innovating) of aspects of the lesson plan. The teacher's self-efficacy supports their effort to enact the lesson plan in the classroom. Regardless of how the lesson actually transpires, the reflective practitioner considers the events of the classroom and reflects on how they fit with the planned lesson (closing the loop to "general model of math teaching"). The reflections impact their self-efficacy and include consultation with information from the community of practice. In some cases, events, aspects of planning or interpretation of information from the community of practice are puzzling. Most often these cause the teacher to seek clarification or fine-tune their method; however, in some cases the questions are not satisfactorily resolved. Instances that leave unresolved questions may be perennial questions or simply instances were a teacher is obliged to move on without fully resolving an issue.

In lesson study the teachers typically begin with an issue or focus that is derived from their classrooms. This leads to consultation of resources (community of practice) and discussion between the teachers that focus on their individually held theories of math teaching. Note that the theories are personalized and may be different for individual teachers within a group. Discussion within the group has a bearing on each teacher's self-efficacy as do classroom observations that occur in the process. The reflective practice continues in this way but the key element of growth is development within each teacher's personalized general model of math teaching facilitating improved self-efficacy.

The algebra tiles vignette illustrates the substantive theory particularly well. Through the vignette concepts from the theory are identified in brackets. In the early planning stages the focal topic of equation solving (specific content) was discussed and the use of algebra tiles (specific method) was mentioned as a possible

method that could be explored. When the technique was initially mentioned it was not discussed to any extent and seemed to simply be a passing topic in the discussion. The participant who ultimately implemented algebra tiles indicated that she had let the topic pass because she had not seen them since teachers' college and did not know enough about them (self-efficacy, specific method).

At a later meeting the researcher raised an issue regarding order of operations within the context of equation solving (general pedagogy). The conversation that arose reflected different grade level perspectives regarding equation solving (subject curriculum, philosophy of subject) and the grade seven teacher articulated the zero-principle that is fundamental to teaching for understanding at his grade level (specific content, specific teaching method). In order to make his point, he demonstrated the zero-principle using algebra tiles (resources) on a SMART board (resources). The tutorial evolved to an exchange of questions (pedagogical questions) and answers (specific teaching method, specific content) that provided detailed information regarding the implementation of algebra tiles in the classroom (PCK).

Two aspects of the dialogue were particularly noteworthy. Firstly, the issue of what resources were available in the school was raised and addressed (resources). This included a mention of the availability of algebra tiles suitable for use with an overhead projector since a SMART board would not be available to the teacher (resources). Secondly, the concern was raised that algebra tiles implement the zero principle and this implies an ability to add and subtract integers. The concern was that the implied ability exceeded the actual ability of many students (pedagogical questions, philosophy of teaching). The resolution to this issue required that the final answer would be positive (specific content) and that students had a visual indicator to assist them with the integer skills.

When the teacher went to pick up the algebra tiles, she reviewed the use of the tiles one last time. This is indicative of a self-reflection (reflective practice) that reassured the participant (self-efficacy) that they understood how to use algebra tiles (PCK). She then implemented the tiles in the classroom (classroom lesson) and later reflected (reflective practice) that it had been successful (self-efficacy). She indicated that she would use them more often and explore other ways of using them in the classroom (pedagogical questions).

The vignette highlights how an area of concern can emerge from a lesson study discussion. A limitation in pedagogical content knowledge prevented the teacher from using algebra tiles even though she had seen them in teachers' college. The lesson study meetings provided detailed information that raised the participant's self-efficacy and facilitated the classroom implementation. It also provided a forum for support and a mechanism for resolving concerns that might have arisen during the implementation. There was evidence that further discussions (within the community of practice) would take place in order to expand the usage of algebra tiles in the grade six class and to share the beneficial experience with another grade six teacher.

The "other's mark" vignette also demonstrates the substantive theory. In this vignette a method of teaching (general pedagogy) was presented by one teacher in response to a discussion about an issue that arose from the classroom. This teacher had learned the technique and, in this sense, it had come from the community of practice. The two teachers who were unfamiliar with the method assessed its merits from the discussion giving them an initial level of self-efficacy about the method. This was not sufficient for them to use the technique but enough to observe the method in an informed fashion. The teacher had strong self-efficacy regarding the method and willingly demonstrated it while the other teachers observed. At the debriefing meeting (reflective practice) one teacher was quite positive but felt that they would need to initially implement the technique in language arts. This implies that they understood the specific technique (general model of math teaching) but had concerns about applying it in math (specific content). The other teacher was reserved because it might interfere with an existing culture of collaboration in her classroom (pedagogical questions).

Discussion

The primary finding of this paper is a mechanism by which lesson study causes change that has been called for (Lewis et al., 2006). The theory highlights the pivotal role of the model of math teaching, held by each teacher, and the importance of there being pedagogical or content knowledge that can be shared. It is through sharing of ideas from each teacher's personalized model of math teaching that other teachers in the group learn new methods. The substantive theory also highlights the supporting role of the community of practice. Most importantly, it demonstrates that teacher self-efficacy is an intermediate factor between this form of reflective practice and the classroom where reflections

take place. The literature indicates that improved teacher self-efficacy corresponds to improved student achievement (Ashton & Webb, 1986; Ross, 1998).

In the theory, teachers are aware of differences in classroom methods and consult colleagues to reconcile those differences (Rowley, 1999; Timperley & Robinson, 2001). The reflective process occurs within the context of teacher's classroom contexts (Hsu, 2004) which facilitates sharing of resources when trying new methods. The theory accounts for improved student achievement because teachers expand or fine tune the repertoire of techniques they use, which constitutes teaching differently (Warfield, Wood, & Lehman, 2005).

The theory did not examine student achievement and relies on the findings in the literature which indicate that improved self-efficacy is indicative of improve student achievement (Ashton & Webb, 1986; Ross, 1998). The theory does not directly explain why teachers with higher self-efficacy would expect more of their students (Tournaki & Podell, 2005). However, learning new teaching techniques and expanding a teacher's repertoire may facilitate better matching of pedagogical techniques with content and needs of students. Persistence in the face of setbacks (Hoy & Spero, 2005) creates more opportunities for students to learn and improve their achievement. It is the antecedent improvement in self-efficacy and its connection to the use of lesson study that the theory explains, not the consequences of improved student achievement, higher expectations or persistence.

Hawkes (2001) did not observe any relationship between self-efficacy and self-reported levels of reflectiveness. This may reflect pedagogical or content limitations within the individual models of math teaching that would constrain self-efficacy changes. Secondly, self-reported reflectiveness may not be consistent with reflective practice in terms of the focus on areas that cause cognitive dissonance within the teacher.

There was little evidence of changes in the philosophical aspects of the teachers' models of math teaching. It is included because there was some evidence and because it is consistent with a continuum of adaptation (Stodolsky & Grossman, 2000) which includes minor changes in practice, pacing changes and, to the extent time permitted, reconceptualization. Philosophy of teaching, as a broad based component of the general model of math teaching, would derive support from a wide array of daily practices and therefore not necessarily change in response to a teacher's pedagogical changes. Lesson study is interpreted as a contributing factor but not of sufficient duration to be a sole cause of changes in a teacher's philosophy of teaching.

The lesson study implementation was largely in agreement with the lesson study method outlined in the literature review. It differed in the level of detail in the lesson plans which did not include a list of anticipated student responses (Fenandez et al., 2003; Meyer, 2005; Yoshida, 1999). This appeared to be due to a limited vision of what constitutes lesson study (Pennisi, 2004) but was reconciled by having some discussion of overall anticipated achievement levels of each grade followed by detailed conversation regarding student responses after the fact. A second minor divergence from the literature was having a pedagogical focus within a vertical alignment objective; this is a minor divergence because of a bias in the literature toward reporting on a single repeated lesson rather than variants such as vertical alignment (Meyer). There was a written report to satisfy administrative requirements while the participants emphasized the overall discussions (Blum et al., 2005).

In practical terms, the participants were observed to have difficulties conveying conceptualizations (Reynolds, Sinatra, & Jetton, 1996) and some pedagogical thoughts (Hartman, 2004; Puchner & Taylor, 2006; Taylor et al., 2005). These are included in the general model of math teaching where personal limitations or different understandings (such as terminologies) are fundamental and, with the development of appropriate technical language, resolvable communication issues (Rock & Wilson, 2005; Yoshida, 1999). Generally, there was sufficient common ground to facilitate changes in practice that were highly contextualized (Hsu, 2004) but have immediate utility in the participants' classrooms (Hartman, 2004; Shulman, 2003). The theory reflects this with common ground being overlap between individuals' enactments of the general model of math teaching and the context arising from the localized format of the reflective practice.

Wheatley (2005) suggests that self-efficacy may be higher when traditional methods of teaching are used while Ross (1998) suggests that having more pedagogical options will benefit teacher self-efficacy. Teachers gained pedagogical options (Watanabe, 2002) through additions to their individualized versions of the general model of math teaching. Self-efficacy changes appeared to be a matter of familiarity with techniques rather than whether they were traditional. This is con-

sistent with higher self-efficacy being related to how routinely, not necessarily how frequently (Ross), a technique is used. More pedagogical options would facilitate better acuity in choosing methods and lead to improved self-efficacy.

Collaboration within lesson study is beneficial (Tschannen-Moran, Hoy, & Hoy, 1998), however, the theory shows that this is within constraints imposed by knowledge and the community of practice. In the absence of hindrance, teachers resolve their instructional concerns and create professional bonds that can be used to resolve future issues both of which positively affect self-efficacy.

Gains in self-efficacy were observed to be most significant in the middle stages of the lesson study. In the early stages, the scope of discussion was generally quite broad, because the teachers have to learn about each other's versions of the general model of math teaching, whereas toward the end there was an air of having discussed what they could. In the middle stages of the process, the discussion was sufficiently focused and novel to create significant opportunities for deep discussions of aspects of the general model of math teaching leading to change.

Conclusions

The theory is consistent with a considerable portion of the research literature and the few discrepancies have been explained. There are areas that require further consideration, such as clarification of the impact lesson study may have on the philosophical portion of the general model of math teaching, but the overall theory provides a framework with which to examine these areas.

Implications of the Theory

The theory provides a linkage between lesson study and self-efficacy which, according to the research literature, contributes to improved student achievement. It demonstrates the central importance of the general model of math teaching and how limitations in PCK can have a direct impact on a teacher's ability to implement techniques they learn through lesson study. The theory illustrates that the community of practice has a secondary supporting role that is important but not imperative to the success of lesson study. Lesson study can impact the principles that teachers use and result in significant conceptual changes provided there are few significant hindrances to change.

Lesson study will only be successful if they form a group that has the internal ability to broaden each teacher's general theories of math teaching. That is, they must be able to share, explain and resolve issues pertaining to details of pedagogical content knowledge and associated content pedagogy. This suggests that reflective practice is likely not a good choice if the content area is weak or unfamiliar to the teachers in a group.

For any particular lesson, having a variety of techniques facilitates pedagogical and PCK comparisons which are beneficial because they allow the teacher to match the choice of method to the specific needs of students. This suggests that the broad range of topics discussed in reflective practice meetings is beneficial. It also suggests that addressing staff complacency is necessary and encouraging ongoing experimentation at a division level combined with sharing of new techniques is beneficial. It also implies the need for an ongoing flow of new ideas, such as one might acquire from subject specific periodicals.

Lastly, the theory demonstrates that the specific advantages of lesson study are in broadening the content and pedagogical repertoires of teachers. It provides a clear picture of what is required to facilitate the process and indicates what leadership could look for in terms of evidence of change.

Future Research

The present theory provides useful insights but would benefit from having causality established. It is presently applicable at the micro-system level (Ashton & Webb, 1986) and could be extended to include divisional or departmental organizational effects. This would extend the theory to include collective efficacy effects and greater intervention by the community of practice.

The present theory has only been developed in the area of mathematics at the intermediate level. It would be useful to see how the theory needs modification for other divisions and subject areas (the need for modifications is implied by Drake, Spillane, & Hufferd-Ackles, 2001). This might provide considerable insights into the organization of knowledge and pedagogy within the general model of math teaching and this might provide deeper insights into the philosophical orientations that teachers hold.

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Development of a Geometric Spatial Visualization Tool

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This paper documents the development of the Geometric Spatial Assessment. We detail the development of this instrument which was designed to identify middle school students' strategies and advancement in understanding of four geometric concept domains (geometric spatial visualization, spatial projection, cardinal directions, and periodic patterns) after experiencing a carefully designed integrated lunar unit. Previous research with students using this lunar unit showed students making significant gains on lunar-related concepts (both scientific and mathematical) on a Lunar Phases Concept Inventory (LPCI) (Lindell & Olsen, 2002). Following the administration of single domain assessments, clinical interviews were conducted to ascertain students' problem solving strategies. Results allowed us to select four suitable multiple-choice items per domain.

Much classroom instruction focused on lunar-phase concepts has been implemented in middle school science classrooms throughout the United States since such concepts are included in both state and national learning standards (National Research Council [NRC], 1996; Texas Education Agency, 2007). Previous research conducted by Wilhelm and Sherrod (2007) with middle school students engaging in this type of instruction has shown them making significant gains on lunar related concepts (both scientific and mathematical) on the Lunar Phases Concept Inventory (Lindell & Olsen, 2002). Upon closer examination of the skills needed to master the lunar-phase concepts, Wilhelm identified four mathematical domains. Ongoing investigations by Wilhelm, Ganesh, Sherrod and Ji (2007) suggested that students improve in four mathematical domains: geometric spatial visualization, spatial projection, cardinal direction, and periodic patterns, after completing a lunar-phase unit of study.

The National Council of Teachers of Mathematics (NCTM, 2000), in *Principles and Standards for School Mathematics*, expounded upon the importance of the development of middle school students' geometric spatial abilities

> Spatial visualization—building and manipulating mental representations of two-and three-dimensional objects and perceiving an object from different perspectives—is an important aspect of geometric thinking. Geometry is a natural place for the development of students' reasoning and justification skills, culminating in work with proof in the secondary grades. Geometric modeling and spatial reasoning offer ways to interpret and describe physical environments and can be important tools in problem solving. (p. 42)

NCTM went on to state that geometric and spatial skills aid students in problem solving and representing their mathematical understanding in both classroom and real-world contexts. For example, an understanding of geometry helps students "make sense of area and fractions, histograms and scatterplots" while well developed spatial skills are needed for "using maps, planning routes, designing floor plans, and creating art" (NCTM, p. 42). In light of these recommendations, the authors sought an instrument that would measure students' mathematical abilities in these four domains believed to be enhanced by engagement in a lunar-phase unit of study. Since no such instrument could be found for middle school students, it became necessary to develop one.

The purpose of this paper is to report the development of this mathematical instrument, the Geometric Spatial Assessment (GSA) designed by Wilhelm et al. (2007). The GSA was designed to measure students' abilities and advancement in understanding of spatial geometric concepts after experiencing a carefully designed integrated lunar-phase unit adapted from a NASA/IDEAS funded curriculum called *Realistic Explorations in Astronomical Learning* (Wilhelm & Wilhelm, 2007). Although the tool was specifically

designed to measure gains in these spatial domains, it was not overtly linked to lunar concepts in order to extend its versatility. We define these four domains as follows: geometric spatial visualization – visualizing geometric spatial features of objects and systems from above/below/within the system's plane; spatial projection – spatially projecting one's self into a different earthly location and visualizing from that global perspective; cardinal directions – north, south, east, west, documenting an object's vector direction in space as a function of time from a given position; periodic patterns – thing(s) occurring at regular intervals of time and/or space. It is anticipated that a robust assessment tool of this nature will validate previous research results regarding students' spatial expertise.

Framework

In the authors' examination of literature targeting connections between spatial abilities and performance in mathematics and science, few recent studies could be located. However, studies over the past three decades have been conducted to examine this relationship (Battista, 1990; Rigney & Lutz, 1976). The literature has shown data supporting a correlation between spatial ability and success on science assessments, such as the Force Concept Inventory (Hake, 2002), graphic performance tests for Engineers (Sorby, 2006), and mental molecular rotation exams in Chemistry (Pritbyl & Bodner, 1987). Other research examined links between students' understanding of the Moon's phases with their spatial visualization ability. Reynolds' (1990) and Wellner's (1995) research findings suggested that students were more likely to report a correct cause of the Moon's phases when they had well-developed projective spatial skills. Black (2005) "hypothesized that a relationship exists between Earth science…conceptual difficulties and spatial ability" and found her results to "suggest that an opportunity may exist to improve Earth science conceptual understanding by development of curricula and interventions that focus on spatial aspects of concepts" (p. 412).

Although some research has alluded to possible connections between students' misconceptions regarding lunar phases and spatial ability (Black, 2005; Wellner, 1995), only one research study thus far has examined possible gains in the students' mathematical abilities after studying lunar concepts. Wilhelm et al. (2007) reported gains in students' LPCI scores on test items that assessed eight science and four imbedded mathematics domains (see Table 1) after participation in a lunar unit. This seven-week lunar unit purposefully included spatial geometric activities and student explorations of the lunar phases through observation, journaling, sketching, three-dimensional modeling, and classroom discussion. However, it is not apparent that if tested outside of the lunar context, students would still show gains in scores on these same mathematical domains.

Lord (1985) suggested that instruction can improve students' visuo-spatial aptitude. Other research has shown a strong link between spatial aptitude and performance in science (Pallrand & Seeber, 1984; Siemankowski & McKnight, 1971). Some researchers also claimed that spatial ability can be developed through instruction (Bishop 1996; Brinkman, 1966; DeBono, 1976). Ben-Chaim, Lappan and Houang (1988) reported that "… after the instruction intervention, middle school students … gained significantly from the train-

Table 1
Concept Domains

Scientific domains		Mathematical domains
A.	Periodicity of moon's Earthly orbit.	Periodic patterns
B.	Periodicity of moon's phases.	Periodic patterns
C.	Moon's orbit direction around Earth as viewed from Space	Geometric spatial visualization, spatial projection
D.	Moon motion	Cardinal directions
E.	Phase and Earth/moon/sun positions	Geometric spatial visualization
F.	Phase–sky location-time	Cardinal directions
G.	Cause of phases	Geometric spatial visualization
H.	Effect of lunar phase with change in Earthly location	Spatial projection

ing program in spatial visualization tasks" (p.66). They also found that gains were maintained over time, and thus argued that once spatial ability is acquired, it can be further developed and hypothesized that "...such abilities are highly responsive to education..." (p.67). Ben-Chaim et al. also discovered that "timing of instruction" in the educational process is important since middle level students gained more than any of the other participating groups.

Method

The initial step in the development of the GSA was the selection of ten multiple-choice items for the domains of periodic patterns and geometric spatial visualization from various existing tests, the creation of ten multiple-choice items for the domain of cardinal directions, and five multiple-choice items for the domain of spatial projection. Each domain was field-tested separately and four items per domain were selected based on item difficulty data. Items on which more than 90% of the students answered correctly and items that more than 90% of the students answered incorrectly were discarded. Four items per domain were selected because they assessed different aspects of each domain. The final instrument consists of sixteen multiple-choice items, each of which offers four or five possible responses (see Appendix).

To identify suitable items to measure abilities in the domain of periodic patterns, two differential aptitude tests were examined (Bennett et al., 1961; The Psychological Corporation, 1990). Items were selected based on one or more of the following criteria: (1) exhibit a pattern or progression, (2) lend themselves to multiple paths to the correct solution, (3) involve a combination of changes, or (4) incorporate the use of angles. Released Texas Assessment of Knowledge and Skills, or TAKS tests (Texas Education Agency, 2007) and reproducible worksheets published by The Center for Applied Research in Education (Publishers' Development Corporation, 1996) were the sources for the ten items addressing the domain of geometric spatial visualization. Items that were selected require application of one or more of the following processes to solve: (1) rotation of solid figures made from cubes, (2) recognition of different views of solid figures, (3) identification of the solid that can be made from several given views, or (4) identification of the three-dimensional solid that can be built with identical cubes based on a two-dimensional chart of the top view and the number of cubes in each column of the structure.

The examination of available tests did not yield suitable items for the domain of cardinal directions. The assessment designers therefore constructed ten items intended to test students' understanding of cardinal directions, their ability to read a map, and their ability to solve word problems involving a combination of these skills. Movements to the right and to the left, as well as a variety of turns were also included in some of the items. Finding items for the domain of spatial projection (as defined by the authors) was unsuccessful. As a result, five items addressing this domain were constructed. These items involved mentally projecting oneself to another location and visualizing from that global perspective.

The validity of the items constructed by the authors was established by a panel of four experts in the content area of mathematics, who had combined experience of more than 25 years working with middle school students. Each member of the panel took the test for each domain, compared their answers, discussed items in which there were differences in interpretation, and negotiated the refinement of items. The items were modified and checked again for possible ambiguities. The domain items were approved by an expert in the fields of mathematics and science education.

The sample used to pilot each domain test was quite large: 122 students for the domain of periodic patterns, 111 for geometric spatial visualization, 119 for cardinal directions and 121 for spatial projection. A large sample size is one of the measures used to determine the relia-

Table 2
Number of Students Interviewed

Mathematical domains	Males	Females
Periodic patterns	3	4
Geo-spatial visualization	3	4
Cardinal directions	3	3
Spatial projection	5	4

Table 3
West Texas Middle School Demographic Information

	Percentage
African American	4.4
Hispanic	12.1
White	80.9
Native American	0.4
Asian/Pacific Islander	2.1
Eligible for free or reduced lunch	12.0

bility of a test. In addition to the piloting of each GSA domain, we conducted clinical interviews with varying numbers of randomly selected students (see Table 2). We acknowledge that the number of clinical interviews was small, but the purpose of these interviews was to ascertain how students were thinking about each concept and whether the test questions would lend themselves with multiple paths towards the correct solution.

Participants

The participants in the field-testing of each single-domain tool were seventh grade students all taught by the same teacher from a west Texas middle school during the Spring term of 2007. The final instrument, which consisted of 16 items, was field-tested during the Fall term of 2007 with a sample of 108 seventh grade students again taught by the same teacher, but who had not participated in the original field-testing of the single-domain items. The middle school's demographic information distribution is shown in Table 3.

Results

We report the single domain results from the Spring 2007 data and follow each domain with excerpts from the clinical interviews that highlight multiple approaches to problem solving. Finally, we end with the reliability coefficient of the final instrument when administered during the Fall 2007 term as a pre-post assessment.

Periodic Patterns

For the periodic patterns domain, ten test items were administered to 122 middle level students. Items 1 through 4 (see *Appendix*) were selected from the periodic patterns assessment tool. Item one was chosen to evaluate how students distinguished between 'shaded and unshaded' regions because this skill is necessary for sketching their observations of the moon. Item two was included because it can be interpreted as a combination of motions in different directions. This combination of motions is usually assumed when observing the Sun and Moon in relation to Earth. Item three not only satisfies the characteristics exhibited by item two, but also indicates different rates of change. Item four was selected because it is the only item related to angles and it also suggests motion. Recognizing angles is important in understanding geometric configurations for particular Moon phases.

When interviewing seven randomly selected students (three male and four female) from the group of 122 concerning the periodic patterns domain, four students indicated that item one (see *Appendix*) was challenging, but was not necessarily the most difficult item. Two students thought the object in this test item was a flag, and all seven stated that they noticed "lines were removed" and used this method to solve the problem. One male said that he just looked at it and "boom, I saw the answer."

One female student claimed she did not know what to do for item two. The other three females explained that "the top (shaded triangle) moved left and the bottom (dot) moved right," "the circle and shaded triangle switched and moved down then up," and "the dot is moving clockwise and the shaded triangle is moving counterclockwise." One male student said "there is a weird motion, they are switching places and moving around" while another said "the shaded triangle is at north, then west, then south, then east," and the third noticed that "the dot rotated to the right and the triangle rotated to the left."

Two-thirds of the males and none of the females considered item four to be the easiest question. Only two students mentioned angles in relation to this item. One male stated that "the first is a skinny angle, then it gets larger, then straight so I followed the pattern. Maybe 45°, 90°, 180°," and one female saw that "angles are formed and each time the angles *largend*." Another male mentioned "movement of lines, one clockwise,

one counterclockwise," and the third observed that "the area on the top section gradually got bigger." The other females saw "a pattern of opening," "opened a bit, then bigger, then straight, then down," and "the lines opened and closed." Multiple strategies were used by students to correctly solve many of the periodic patterns test items.

Cardinal Directions

Ten cardinal direction test items were administered to 119 middle level students. The selections from the domain of cardinal directions were items 5 through 8 (see Appendix). We decided on items five and six because they involved multiple processes and require students to use a well developed sense of direction. Item seven was chosen to evaluate students' map-reading skills as well as their sense of direction. These skills are necessary for identifying different parts of the world in relation to the students' location. Item eight is relevant to this tool because it requires multiple skills to visualize the scenario and correctly determine direction. This use of multiple skills is frequently required throughout the lunar unit to correctly identify the position of the Moon at a particular time and to predict how it would appear to viewers on the other side of the world.

Six interviews were conducted (three male and three female) for the domain of cardinal directions. Two males found item five to be somewhat difficult. The explanation given by one male was, "I imagined four people … the person to the right is facing east. I used the compass rose to help." One female stated "I just pictured it in my head."

Two females and one male reported that they found item eight to be difficult. All students shared similar strategies for solving this problem. One male explained, "I just imagined north and south at Lowery Field (a local football stadium)," while one female said, "It was confusing me so I drew a picture. I pictured Texas Tech stadium to find the answer." Another female stated, "I drew a compass rose, found east and looked across to get my answer," while a male shared this, "If those opposite turn right, then I'd have to turn left to face the same direction."

Geometric Spatial Visualization

For the domain of geometric spatial visualization, ten items were administered to 111 students. Of these, items 9 through 12 (see *Appendix*) were chosen. We selected item nine because it requires the incorporation of three different two-dimensional views to mentally construct a solid figure, which is a required skill of the lunar unit. Item ten was chosen because it requires the ability to perceive a solid figure from one view and select the two-dimensional representation of that view. These skills are necessary for individuals to be able to visualize the Moon's appearance from multiple viewpoints above/below/within the system's plane. Item 11 was selected because it requires students to identify a plane (two-dimensional) figure that represents the top view of a complex (three-dimensional) solid object. The ability to use a two-dimensional representation to identify a representation of a three-dimensional object is an essential skill for sketching phases of the moon. Item 12 was included because it taps the skill of creating a solid figure from a description of a plane view. This skill is instrumental in constructing a three-dimensional model of the moon, given one of its phases. When interviewing seven randomly selected students (four female and three male) on the geometric spatial visualization domain items, three females said they found the item 11 to be the most difficult. During the interview one male explained that he solved the problem as follows: "I imagined a little cone in my head, with a paper passing through, then compared the answers to what was in my head…" Another male stated, "I thought of it as if I was looking at it from the top. It was easy." One female said, "I tried *smooshing* it down so I could see it from the top …" while another stated, "I thought of the top view and looked at the choices. It was hard."

Item 12 for geometric spatial visualization was considered difficult by three males and one female. One male said, "This confused me at first, then I looked at the choices. I compared the answer choices to the chart. I went row by row and checked each." Another male responded this way, "It took me a long time. I just kept looking at the height of the squares." One female said, " I looked at it like it was pushed down and compared it to the choices" while another responded, "I matched the blocks in my head to the chart, then I just kept going around and matching." Once again, students used multiple strategies to arrive at the correct solution.

Spatial Projection

Five spatial projection test items were administered to 121 students. Since the domain of spatial projection was tested with five items, only one item was excluded because it was linked to item 14 (see *Appendix*) in such a way that it could not stand alone. Items 13 through 16 (see *Appendix*) were selected because the assessment designers believed that these items tested students' ability to project themselves in space to determine how an object anchored in a particular place would appear to someone in another location. This was supported by the

following interview responses.

The interview data as well as the domain test scores showed that the nine (five males and four females) interviewed students found spatial projection to be the most challenging of the four domains. Two males and four females thought that item 15 was the most difficult. The following dialogue illustrates how one male claimed he solved the problem.

Male: I put a map in my head and a dot for him, then I figured out the time zones. I have a general idea where they are. So I made the sun move in the sky until I found the answer.

Interviewer: Have you studied time zones?

Male: No, I learned about time zones by talking to people and looking at maps outside of school. I can freeze pictures in my head and go back to them when I need them.

Another male student responded, "My grandmother used to live in California and she told me that her shadow would be shorter than mine in Texas, if we were looking at them at the same time." One female stated "I had to read it twice. I thought where the shadow was and I just guessed," while another female offered this: "I tried to think of the person west and thought it [shadow] could be longer."

Final Instrument

After other minor revisions, the instrument (see Appendix) was finalized. This final 16-item instrument was used as a pre-post test for the integrated lunar unit that incorporated the REAL curriculum during the Fall 2007 term. Reliability of the sample scores was calculated using the Cronbach's alpha; this function measures the internal consistency for each item and indicates a lower limit on the stability of students' scores. For this sample, the coefficient alpha calculated was 0.434 for the pretest and 0.498 for the posttest.

Discussion

From the clinical interviews there was rich emergent data describing strategies employed such as that reported in the dialogue between two male participants and an interviewer. Both of these males referred to information gained from talking with adults outside of school "...I learned about time zones from *talking to people* and looking at maps outside of school", and "*My grandmother* used to live in California and she *told* me that ..." This observation supports one of the findings reported by Capraro (2001), who claimed that performance on a test of geometric spatial visualization appears to be affected by activities such as parents and other adults talking to children and showing them how to perform certain physical tasks. The methods used by the students to solve the problems on the various instruments were very informative and often displayed multiple paths to arrive at the correct solution, which was one of the specific design features of this assessment.

Since Chronbach's alpha measures the average correlation of test items with each other, and the GSA was purposely designed to measure understanding in four domains as opposed to a single construct, it is not surprising that the coefficient alphas for both the pre- and post-tests were low. The authors plan to conduct a test-retest with another group of middle school students in the near future. A test-retest reliability index will provide greater insight of the GSA's potential to yield consistent scores with middle school students.

Conclusion and Importance

We believe that one cannot understand lunar phases without a developed understanding of four spatial concepts: 1) *geometric spatial visualization,* 2) *spatial projection,* 3) *cardinal directions,* and 4) *periodic patterns*. We have created an assessment tool that will be used pre and post instructional intervention to identify the development of understanding of these four spatial concepts. Because previous research with students using a lunar unit showed students making significant gains on LPCI concepts, we developed this instrument to filter out the science domains and focus only on the gains made on spatial concepts. If we confirm (via our newly designed geometric spatial assessment) that this integrated lunar unit does indeed further students' understandings on geometric spatial concepts, more integrated units can be developed that place mathematics in multiple contexts. Further research is needed to study this symbiotic relationship between spatial mathematics and scientific understandings.

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Appendix

Geometric Spatial Assessment
(Wilhelm, Ganesh, Sherrod, & Ji, 2007)

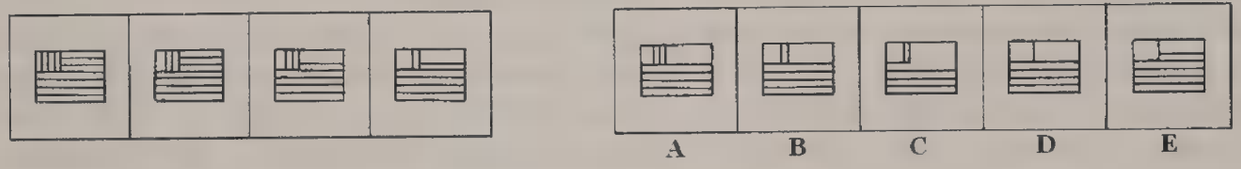
Name _____ Date _____

Circle One: Male Female

On the left of each row you will find 4 figures or designs in a series. Please look for a pattern and find the best choice for the fifth figure from the list of choices on the right.

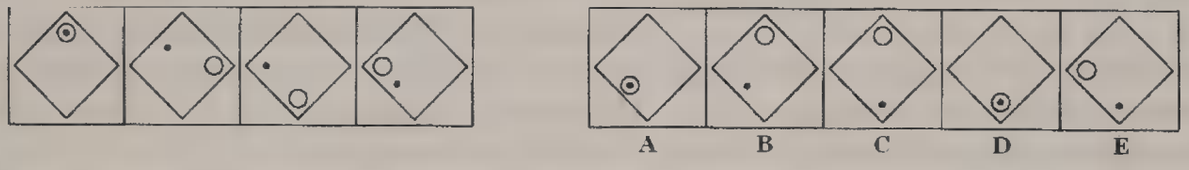
Circle the letter of what you believe to be the 5th figure or design in the series.

1.

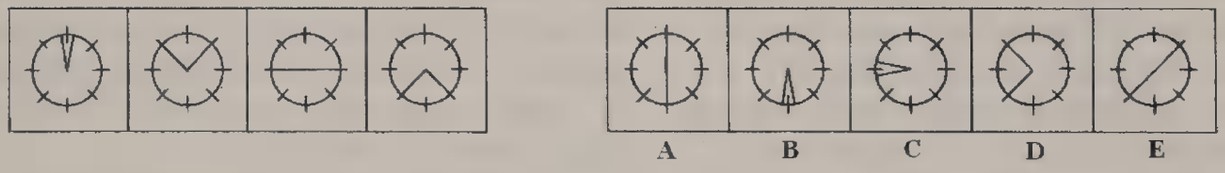


2.

3.



4.



5. You and three of your friends have formed a circle by facing each other and clasping hands. You are facing South. Which of the following directions is the friend to your right facing?

(A) South (B) East (C) West (D) South West

6. One of your friends leaves the circle. You and your two remaining friends form a new circle. You are still facing South. Which of the following directions is the friend to your left now facing?

(A) Northeast (B) Southwest (C) Northwest (D) Southeast

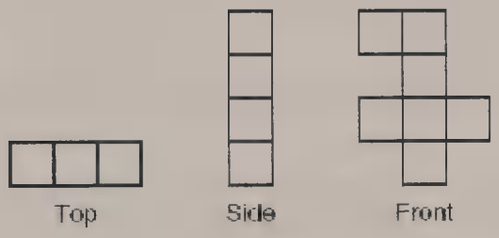
7. In the map below, Wyoming is west of which of the following states?

(A) South Dakota (B) Montana (C) Colorado (D) Idaho

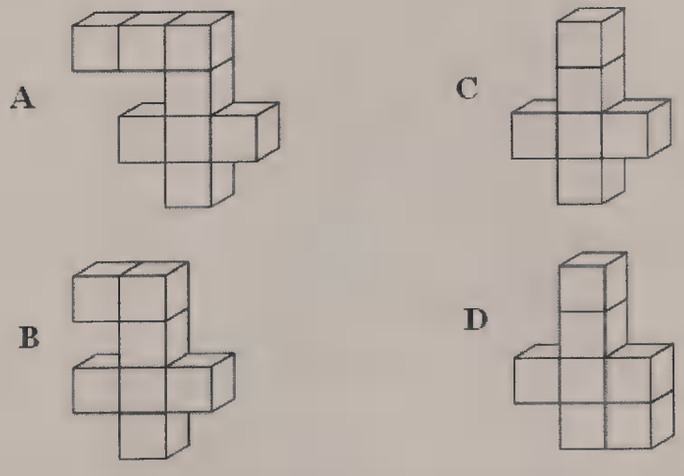
8. You are watching a soccer game, seated in the middle of the section facing East. The fans seated directly across the field, on the other side of the stadium, turn toward their right as the home team kicks a goal. Toward which direction are they facing?

(A) North (B) South (C) East (D) West

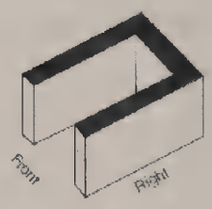
9. The top, side, and front views of a solid figure made of cubes are shown below.

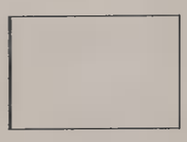


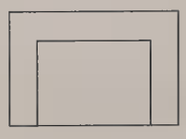
Which solid figure is best represented by these views?



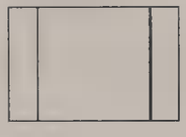
10. Which of the following best represents the front view of the solid shown below?



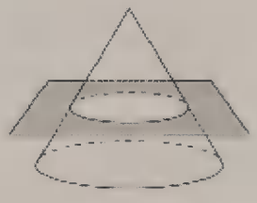
A 

B 

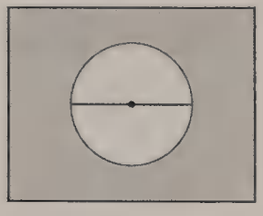
C

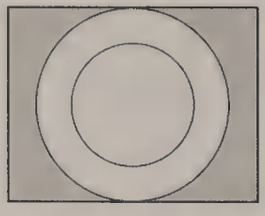
D 

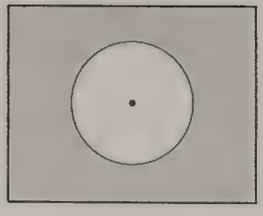
11. A table was designed to appear to be a cone with a wooden board passing through it.

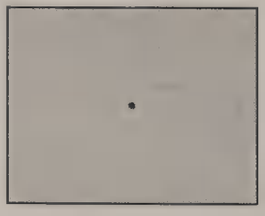


Which of the following best represents the view from above the table?

A 

C 

B 

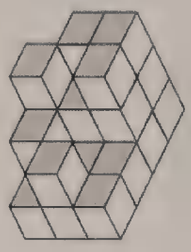
D 

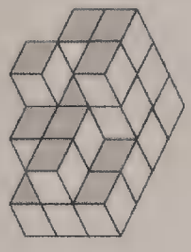
12. The drawing below shows both the top view of a solid structure built with identical cubes as well as the number of cubes in each column of the structure.

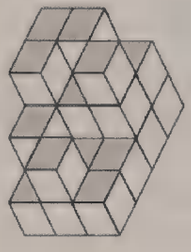
2	3	3
3	2	3
2	1	1
1	2	1

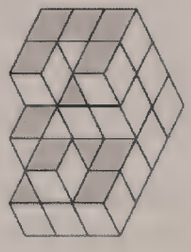
Front

Which 3-dimensional view best represents the same structure?

A 

C 

B 

D 

13. Two boats are approaching a dock on which the Texas flag is flying. Boat One is approaching from the East and Boat Two is approaching from the West. The captain of Boat One would see the flag as in the picture below. Where on the flag would the captain of Boat Two see the Lone Star?

(A) Right (B) Left (C) West (D) South West

14. You are seated on a carousel, also known as a merry-go-round, facing due west. It is close to sunset and the sun is directly in front of you. Keeping your eyes fixed so that you are looking between the ears of your carousel horse for the entire ride, through which of the following ranges must the carousel rotate so that the sun would no longer be in your view?

(A) 10-30° (B) 60-80° (C) 100-120° (D) 330-350°

Questions 15 & 16

15. It is evening and your shadow is as shown in the picture. Your cousin, who lives in another state 200 miles west, is looking at his shadow at the same time. How would his shadow compare to yours?

(A) the same (B) longer (C) shorter (D) on the other side

16. It is Sunrise where you live and your grandmother, who lives 100 miles East of you, is also looking at her shadow at the same time. How would her shadow compare to yours?

(A) the same (B) longer (C) shorter (D) on the other side

Note:

Items 1 & 4 were taken from Differential Aptitude Tests, Form L (1961) The Psychological Corporation, New York, NY.

Items 2 & 3 were taken from Differential Aptitude Tests, Level 1 Form C (1961) The Psychological Corporation, New York, NY.

Items 9 & 10 were taken from TAKS test released in Spring 2004 (Grades 7 & 11)

Retrieved March 29, 1007 from: http://www.tea.state.tx.us/student.assessment/resources/release/taks/index.html

Items 11 & 12 were taken from TAKS test released in April 2006 (Grades 10 & 9) Retrieved March 29, 2007 from: http://www.tea.state.tx.us/student.assessment/resources/release/taks/index.html

Science Teacher Efficacy and Outcome Expectancy as Predictors of Students' End-of-Instruction (EOI) Biology I Test Scores

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The purpose of this study was to compare teacher efficacy beliefs of secondary Biology I teachers whose students' mean scores on the statewide End-of-Instruction (EOI) Biology I test met or exceeded the state academic proficiency level (Proficient Group) to teacher efficacy beliefs of secondary Biology I teachers whose students' mean scores on the EOI Biology I test fell below the state academic proficiency level (Non-proficient Group). The mean difference on the Personal Science Teaching Efficacy (PSTE) subscale scores between the two groups was not statistically significant. This indicates that personal science teaching efficacy was not statistically related to how a teacher's students scored on the EOI Biology I test.

The mean difference on the Science Teaching Outcome Expectancy (STOE) subscale scores demonstrated a statistically significant difference between the science teaching outcome expectancy of the Non-proficient Group and Proficient Group teachers. Proficient Group teachers had significantly higher STOE scores than teachers Non-proficient Group teachers. This finding suggests that End-of-Instruction Biology I test scores were related to the expectations that a teacher held for his/her students to learn biology regardless of student home environment, availability of classroom materials, or student motivation.

Concerns about the quality of America's education system and subsequent reform efforts permeated the 20th century. With the dawn of the 21st century, the basis for these concerns broadened from the potential economic loss from decreased human productivity to include human safety and national security. As the *U.S. Commission on National Security in the Twenty-First Century* (2001) reported,

> The inadequacies of our systems of research and education pose a greater threat to U.S. national security over the next quarter century than any potential conventional war that we might imagine. American national leadership must understand these deficiencies as threats to national security. If we do not invest heavily and wisely in rebuilding these two core strengths, America will be incapable of maintaining its global position long into the 21st century. (p. 9)

This statement was, in part, a response to the 1995, 1999, and 2003 Third International Mathematics and Science Study (TIMSS) reports by the National Center for Education Statistics (Gonzales et al., 2004). The TIMSS reports, supported byresults from the 2000 National Assessment of Educational Progress (National Assessment Governing Board, 2002), revealed that science and mathematics education reform efforts were not producing the expected increase in scientific knowledge among American children when compared to children from other countries or when measured against the *National Science Education Standards* (National Research Council, 1996).

Raising educational expectations in America's schools and sustaining successful reforms require the efforts of not only state education agencies and local school districts but also individual administrators and teachers. To expedite education reform, President Bush signed into action the No Child Left Behind Act (Public Law 107-110) in 2002. No Child Left Behind (NCLB) uses accountability as a crucial step in addressing the achievement gaps that exist among ethnic and socioeconomic groups. To narrow these gaps and raise student test scores, every state is required to set standards for student performance for grade-level achievement and develop a system to measure the progress of all students and subgroups of students. Additionally, NCLB pledged to have a highly qualified teacher in every classroom by the end of the 2005-2006 school year. According to the U.S. Department of Education (2004), teachers are 'highly qualified' if they have a bachelor's degree, certification or licensure to teach in the state of their employment, and proven

knowledge of the subjects they teach. NCLB propounds that establishing state standards, which highly qualified teachers use as a guide, will ensure that all children – from every ethnic and cultural background – will receive a quality education and the opportunity to realize their academic potential.

NCLB initially required schools to demonstrate evidence of adequate yearly progress toward meeting state learning standards for all groups of students. States were required to develop target starting goals for adequate yearly progress and raise the bar in gradual increments so that 100% of the students in the state were proficient on state assessments by the 2013-2014 school year (U.S. Department of Education, 2003). Schools that failed to meet or exceed the annual measurable objective risked losing Federal Title I funding.

In the state where this study was initiated, the End-of-Instruction (EOI) Biology I test was implemented to provide evidence of students' levels of proficiency at the end of instruction in Biology I. On the EOI Biology I test, students respond to a variety of items linked to both the process and content standards identified in the Biology I state standards. A student's EOI Biology I score is recorded on his/her high school transcript. EOI scores for each high school are used to calculate a school's 'report card' that evaluates a school's performance compared to other schools in the state. Thus, the EOI tests have significant consequences for the school as a whole if scores fall below the state's academic level of proficiency.

Statement of the Problem

The United States expects all its children to receive a quality education from highly qualified teachers, providing all children an opportunity to reach an established level of proficiency. While most teachers in the study state have achieved the status of 'highly qualified' according to NCLB, students of some teachers score higher on the state mandated EOI Biology I test than students of other teachers. Researchers have argued that teachers' attitudes and self-efficacy beliefs play a significant role in the actions taken in their classroom, time spent on lesson preparation, and implementation of innovative reform practices (Ashton & Webb, 1986; Gibson & Dembo, 1984). In addition, teacher efficacy (Allinder, 1995; Rubeck & Enochs, 1991) and attitudes (Koballa & Crawley, 1985) that high school science teachers develop about science are related to the achievements and attitudes of their students.

Researchers has emphasized that teacher quality is the single most important factor for increasing student achievement. At the same time, TIMSS results reveal that the U.S. science and mathematics education reform efforts are not producing the expected increase in scientific knowledge among American children (Calsyn, Gonzales, & Frase, 1999). While the amount of research related to efficacy beliefs of elementary teachers is extensive, comparatively less research focuses on efficacy beliefs of high school science teachers — particularly high school biology teachers. In addition, there has been little research that describes the characteristics, attitudes, and beliefs of high school science teachers whose students achieve at or above the academic proficiency level compared to the characteristics, attitudes, and beliefs of science teachers whose students fail to achieve at a level of academic proficiency.

Theoretical Framework

Over the past twenty-five years, research suggests that a teacher's sense of self-efficacy plays a powerful role in student academic achievement (Allinder, 1995; Armor et al., 1976; Ashton & Webb, 1986), as well as in receptiveness to implementing new instructional practices to meet the needs of all students (Berman & Mclaughlin, 1977; Guskey, 1988) and commitment to teaching (Evans & Tribble, 1986). Within the context of teaching efficacy, two sets of beliefs are acknowledged — personal teaching efficacy and general teaching efficacy or outcome expectancy (Ashton & Webb; Gibson & Dembo, 1984). Personal teaching efficacy reflects a teacher's confidence in his/her personal capabilities to successfully accomplish a specific teaching task in a particular context. In contrast, outcome expectancy is defined as the belief that skillful instruction can offset the effects of variables beyond the teacher's control (Gibson & Dembo; Tschannen-Moran, Woolfolk-Hoy, & Hoy, 1998).

Differences in efficacy can be explained using Bandura's (1986, 1997) Social Cognitive Theory that identified teacher efficacy as "a cognitive process in which people construct beliefs about their capacity to perform at a given level of attainment" (Tschannen-Moran et al., p. 203). Through cognitive processes and life experiences, people develop a generalized expectancy about specific action-outcome relationships. Bandura argued that human behavior is influenced by the individual's beliefs regarding two classes of expectations: outcome expectancy, an individual's estimate of the likely consequences of performing that task at the ex-

pected level of competence, and efficacy expectation, the personal conviction that one can successfully execute the behavior required to perform the task (Bandura, 1986).

A growing body of empirical evidence indicates teacher quality to be the most important factor in predicting student achievement (Eide, Golhaber, & Brewer, 2004). Thus, teacher quality is being utilized as the infrastructure behind the anticipated success of the NCLB Act. While some research leans toward improving teacher quality to increase positive change in student achievement (Darling-Hammond, 1999; Goldhaber & Anthony, 2003), other research supports teaching efficacy as the critical avenue to improving student test scores (Armor et al., 1976; Ashton & Webb, 1986; Ramey-Gassert, Shroyer, & Staver, 1996). Teachers demonstrating a strong sense of efficacy invest more effort in teaching, (Tschannen-Moran & Hoy, 2001), try innovative ideas (Berman, McLaughlin, Bass, Pauly, & Zellman, 1977; Guskey, 1988), conduct student-centered (as opposed to teacher centered) classroom environments (Ramey-Gassert et al.), and demonstrate patience when working with students struggling with a concept (Ashton & Webb; Gibson & Dembo, 1984). While Bandura's Social Cognitive Theory and self-efficacy beliefs may lend themselves to the idealism of the highly qualified teacher described in NCLB, the teacher attributes that NCLB uses to define a highly qualified teacher – degree, certification, and proven knowledge — differ from those that researchers of teaching efficacy use to identify an effective teacher.

The purpose of this study was to compare teacher efficacy beliefs of Biology I teachers whose students' mean scores on the statewide End-of-Instruction Biology I test met or exceeded the state academic proficiency level (Proficient Group) to Biology I teachers whose students' mean scores on the EOI Biology I test fell below the state academic proficiency level (Non-proficient Group). This study was conducted statewide as teachers of proficient and non-proficient scoring students are found in all geographic regions of the state. The focus of the study was on the differences between these two groups of teachers regardless of where they were teaching. Specifically, the following research questions were addressed:

Is there a significant difference between the Personal Science Teaching Efficacy (PSTE) of Biology teachers whose students' mean scores on the EOI Biology I test met or exceeded the level of proficiency and the PSTE of Biology I teachers whose students' mean scores on the EOI Biology I test fell below the level of proficiency?

Is there a significant difference between the Science Teaching Outcome Expectancy (STOE) of Biology teachers whose students' mean scores on the EOI Biology I test met or exceeded the level of proficiency and the STOE of Biology I teachers whose students' mean scores on the EOI Biology I test fell below the level of proficiency.

Methodology

A survey design (Creswell, 2003) was employed to collect quantitative data obtained from a Teacher Attribute Questionnaire and the Science Teaching Efficacy Belief Instrument (STEBI). In addition, EOI Biology I test scores were obtained from the State Department of Education (SDE). A survey design was selected since it provided a quantitative description of teacher and school attributes, as well as qualitative beliefs and opinions of high school science teachers who teach Biology I. This study was conducted using a voluntary sample of the total population of biology teachers in the state.

Participants

The participants were high school teachers who taught Biology I during the time of this study. Names of science teachers were obtained from the Open-Records department at the State Department of Education. To ensure a high response rate from participants, Salant and Dillman (1994) suggest a four-phase administration process. The first mailing was sent to 750 Biology teachers during the second week in October containing a short notice informing teachers of the research study. The second mailing, containing the Teacher Attribute Questionnaire, the STEBI, an informed consent form, and a pre-addressed, stamped return envelope, was sent approximately eight days later. The third mailing was sent ten days after the second, encouraging the teachers who had not yet returned their research packet to do so. Although Salant and Dillman suggest a fourth mail-out to all non-responding participants to increase the participation response rate, the fourth mailing was not conducted due to the high response rate of the original mailings.

Participants for this study were obtained from a population of Biology I teachers who voluntarily returned the Teacher Attribute Questionnaire, STEBI, and an informed consent form. Seven hundred and fifty packages were mailed with 214 teachers responding. Not all of the participants were used in the study for three

Table 1
Demographics of Biology I Teacher Participants (N=196)

Category		Number	Percent (%)
	Male	79	40.3%
	Female	117	59.7%
Age			
	25 and under	4	2.0%
	26-30	25	12.8%
	31-35	35	17.9%
	36-40	18	9.2%
	41-45	24	12.2%
	46-50	32	16.3%
	51-55	32	16.3%
	56-60	17	8.7%
	61 and above	9	4.6%
Degree			
	Bachelors	129	65.8%
	Masters	65	33.2%
	Doctorate	2	1.0%
Certification			
	Traditional	167	85.2%
	Alternative	29	14.8%
School location (community size)			
	Rural, < 10,000	120	61.2%
	Suburban	53	27.0%
	Urban, > 100,000	23	11.7%
Teach AP Biology			
	No	166	84.7%
	Yes	30	15.3%
Preparedness of students			
	No	60	30.6%
	Yes	136	69.4%

reasons: forms were not filled out completely; one or more forms were not returned; or, the participating teacher did not teach a Biology I class the previous year in the same school district. Information from 196 of the responding participants was used in this study; thus, over a 25% response rate from the total biology teacher population was used. Demographic information obtained from the Teacher Attribute Questionnaire is given in Table 1.

Instrumentation

Teacher Attribute Questionnaire: A four page questionnaire, including selected choice answers as well as open-ended responses, was designed to gather information about the teacher's personal background and academic background (age, gender, national certification status, college degree), school demographics (school and class size, school location), and teaching experience (professional affiliations, professional development involvement, pedagogy, EOI preparation). The information was utilized to identify which teacher attributes were associated with proficient or non-proficient EOI Biology I test scores.

Science Teaching Efficacy Belief Instrument (STEBI): Quantitative data was collected through the administration of the Science Teaching Efficacy Belief Instrument (STEBI). Bandura (1986) describes self-efficacy as a situation specific construct. Hence, it is important to select an instrument designed to predict science teaching efficacy and not merely generalized efficacy beliefs. Riggs and Enochs (1990) developed the STEBI which contains two unrelated subscales: the *Personal Science Teaching Efficacy Belief* (PSTE) scale and the *Science Teaching Outcome Expectancy* (STOE) scale. Riggs and Enochs reported reliability analysis of alpha coefficients of 0.92 for the PSTE scale and 0.77 for the STOE. This instrument was designed to specifically assess personal teaching efficacy and outcome expectancy beliefs of inservice science teachers.

The STEBI consists of 25 items, 13 of which assess personal science teaching efficacy and 12 of which assess science teaching outcome expectancy. High school Biology teachers were asked to compare their beliefs to each of the 25 items. The responses on the STEBI were scored on a 5-point Likert-scale format.

These two separate and unrelated subscale scores were recorded for each participant. In accordance with Bandura's (1977, 1997) self-efficacy theory, a high score on the personal science teaching efficacy belief subscale indicates that science teachers are highly confident about their ability to effectively teach science to all students. These teachers are also more likely to implement new teaching strategies (Guskey, 1988), encourage student centered classroom atmospheres (Enochs, Scharmann, & Riggs, 1995; Guskey, 1984), and work patiently with academically-challenged students (Allinder, 1995). Teachers with low personal science teaching efficacy are more likely to become frustrated with students who experience difficulty understanding science concepts and thus become critical of students when they make science concept errors (Ashton & Webb, 1986). These teachers feel uncomfortable about their ability to teach science content and process skills through an inquiry methodology in accordance with the *National Science Education Standards* (Gibson & Dembo, 1984; NRC, 1996).

Teaching outcome expectancy is defined as the belief that effective teaching will have a positive effect on student learning regardless of environmental factors (e.g., family background, IQ, and school conditions) (Tschannen-Moran & Hoy, 2001). Teachers who score high on the science teaching outcome expectancy subscale feel confident about their ability to positively influence students' science understanding, regardless of outside factors (Riggs & Enochs, 1990). On the other hand, teachers who score low tend to perceive the students' external circumstances (i.e., unsupportive home environment, low grades, or lack of classroom supplies and lab equipment) as being serious obstacles to the student's science achievement (Guskey, 1988).

End-of-Instruction Biology I Test: NCLB required all states to measure students' progress in science at least once in each of three grade spans (3-5, 6-9, 10-12) beginning in 2007 (U.S. Department of Education, 2005). Consequently, state legislators mandated a criterion-referenced test for students at the completion of Biology I. According to the State Department of Education, the purpose of the EOI Biology I test is to measure students' levels of science proficiency which consist of an understanding of scientific methods, as well as biological concepts. For schools with the traditional nine-month, two-semester course, students take the EOI Biology I test during a three-week period falling between the last two weeks of April and the first week of May. Student test results are sent to schools in early fall during the same calendar year.

EOI Biology I test results for each teacher participating in this study were obtained from the Accountability and Assessment division of the State Department of Education (SDE). Once a teacher returned the questionnaire and efficacy instrument, a formal open records request was sent to the SDE, requesting the participating teacher's mean student EOI Biology I test scores. The SDE then sent a summary report for the district and individual school where that teacher instructed.

Results

Personal Science Teaching Efficacy (PSTE): The first research question in this study explored the differences in the personal science teaching efficacy of Biology teachers whose students' mean scores on the EOI Biology I test met or exceeded the level of proficiency (700 and above) – Proficient Group - and the Biology teachers whose students' mean scores on the EOI Biology I test fell below the level of proficiency (below 700) – Non-proficient Group. The 13 PSTE subscale items were analyzed for the purpose of making group comparisons. Descriptive statistics reporting the mean and standard deviation of Proficient and Non-proficient Groups are given in Table 2.

The Proficient Group teachers reported the same

Table 2
Means, Standard Deviations, and Results of the Independent Sample t-Test for the Personal Science Teaching Efficacy and EOI Teacher Division Groups (N=196)

EOI group		Mean		Standard deviation	
Non-proficient		55.68		5.511	
Proficient		55.59		4.533	
Mean difference	Standard error of mean difference	95% confidence interval of the difference		t (194)	p
		Lower	Upper		
.09	.935	-1.752	1.936	.098	.922

mean PSTE score as the Non-proficient Group teachers. However, the Proficient-Group teachers had a smaller standard deviation (4.533) indicating that they had less variance in their responses. After noting these descriptive differences, an independent-samples t-test was used to determine if the mean difference was statistically significant. The 95% confidence interval was calculated for the mean comparison. The mean difference on the PSTE subscale scores between the Proficient Group and the Non-proficient Group teachers was not statistically significant [t (194) = .098, p = .922]. This indicates that personal science teaching efficacy was not statistically related to how a teacher's students scored on the EOI Biology I test.

To further explore as to why no significant difference in PSTE existed between the proficient and non-proficient groups of teachers, the 196 PSTE scores were arranged from greatest to least and then separated into four quartiles of 49 scores each. In Figure 1, the 1st quartile represents the 49 participants with the highest PSTE scores, while the 4th quartile represents the 49 participants with the lowest PSTE scores. Seven teachers in the 1st quartile, sixteen teachers in the 2nd quartile, nine in the 3rd quartile, and nine in the 4th quartile had mean student EOI Biology I scores at or above 700 (the state proficiency level for Biology I). A Pearson correlation coefficient measure was calculated between the number of teachers with mean student EOI Biology I scores at or above 700 and the quartile number where the corresponding teacher's PSTE score fell. An r-value of 0.033 was calculated. Due to the low r-value between the quartile numbers and the number of teachers, the assumption was made that the variables were not bivariately normally distributed. This means that the scores of one variable (number of teachers with average student EOI scores at or above 700) were independent of the scores on the second variable (the quartile number where the corresponding teachers PSTE score fell). To further measure the strength of the relationship between the two variables, the correlation value was squared providing an r^2 value of 0.0011, thus concluding that only 0.1 percent of the variance of the EOI score was accounted for by Biology teachers' PSTE scores.

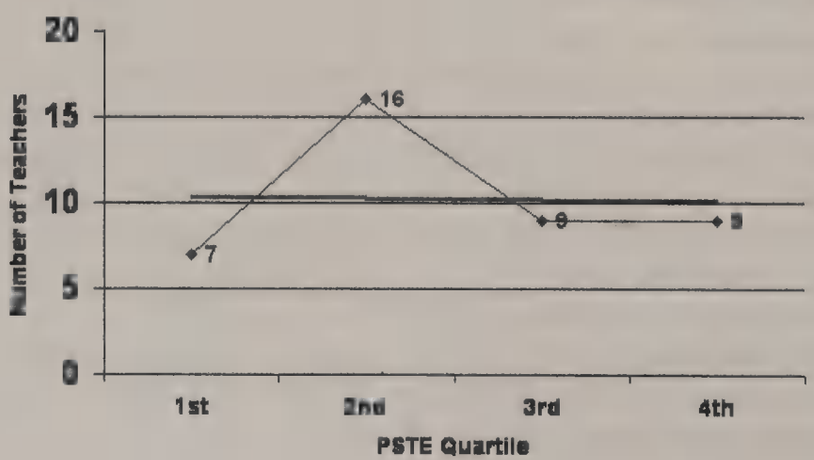

Figure 1. Number of teachers with average EOI scores at or above 700 by PSTE quartile.

Table 3

Means, Standard Deviations, and Results of the Independent Sample t-Test for the Outcome Expectancy and EOI Teacher Division Groups (N=196)

EOI teacher group		Mean		Standard deviation	
Non-proficient		37.79		4.685	
Proficient		39.98		4.618	
Mean difference	Standard error of mean difference	95% confidence interval of the difference		*t* (194)	*p*
		Lower	Upper		
-2.19	.820	-3.806	-.571	-2.668	.008

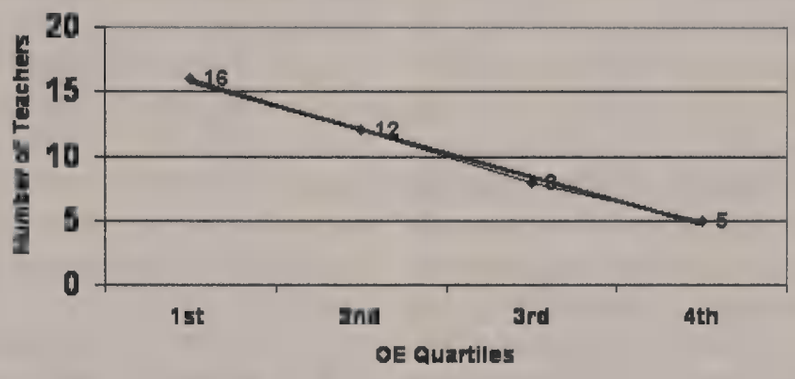

Figure 2. Number of teachers with average EOI scores at or above 700 by oe quartiles.

These findings support the conclusion that there was no statistical difference in the PSTE scores between Proficient Group and Non-proficient Group teachers. The two groups have similar beliefs about their effectiveness to teach science.

Science Teaching Outcome Expectancy (STOE): The second research question examined the difference in the science teaching outcome expectancy of Biology teachers whose students' mean scores on the EOI Biology I test met or exceeded the level of proficiency (700 or above) to those of Biology I teachers whose students' mean scores on the EOI Biology I test fell below the level of proficiency (below 700). One-hundred fifty-five teachers reported mean student EOI scores below the state proficiency level (Non-proficient Group), while forty-one teachers reported mean student EOI scores at or above the state proficiency level (Proficient Group). The Non-proficient Group teachers reported a mean STOE of 37.79, while the Proficient Group teachers reported a mean of 39.98. When analyzed as a whole construct, quantitative data analysis of the STOE subscale on the STEBI demonstrated a statistically significant difference between the science teaching outcome expectancy of the Non-proficient Group and Proficient Group teachers. Proficient Group teachers had significantly higher [(t (194) = 2.668, p = .008] STOE scores than Non-proficient Group teachers, at a 95% level of proficiency. Both groups had a standard deviation of 4.6, meaning that both groups of teachers had the same variance in their responses (Table 3).

To further explore the significant difference in outcome expectancy between the Proficient Group and Non-proficient Group teachers, the 196 STOE scores were arranged from greatest to least and then separated into four quartiles of 49 scores each. In Figure 2, the 1st quartile represents the 49 participants with the highest STOE scores, while the 4th quartile represents the 49 participants with the lowest STOE scores. Sixteen teachers in the 1st quartile, twelve teachers in the 2nd quartile, eight in the 3rd quartile, and five in the 4th quartile had mean EOI scores at 700 or greater. A Pearson correlation coefficient measure was calculated between the number of teachers with mean student EOI Biology I scores at or above 700 and the quartile number where the corresponding teachers STOE score fell. An r-value of 0.998 was calculated. Due to the high r-value between the quartile number and the number of teachers who had mean student scores who met or exceeded the state academic proficiency level on the EOI

Biology I test, the assumption can be made that the variables were bivariately normally distributed, meaning that the scores of one variable (number of teachers with student mean EOI scores at or above 700) were related to the scores of the second variable (the quartile number where the corresponding teachers STOE score fell). To further measure the strength of the relationship between the two variables the correlation value was squared providing an r^2 value of 0.996, concluding that 99.6 percent of the variance of the EOI Biology I test was accounted for by the Biology teachers' STOE scores.

Discussion

Personal Science Teaching Efficacy (PSTE): The findings in this study suggest that the beliefs that Biology teachers hold in their science content knowledge and ability to teach science effectively were independent of student EOI Biology I scores. Pajares (2002) explains that self-efficacy influences the choices people make and the course of action pursued; thus, individuals tend to select tasks and activities in which they feel competent and confident, and avoid those in which they do not. The non-significant correlation between the two groups in this study might be interpreted that some of the Biology teachers selected the content and process skills familiar and important to them personally, instead of addressing all the standards the state requires. But regardless of a teacher's belief in their personal ability to teach science, students' scores may be independent of their teacher's belief.

Tschannen-Moran et al. (1998) state that personal teaching efficacy influences the goals teachers promote in their classrooms. Teachers with high levels of efficacy are more likely to seek out resources, develop challenging lessons, persist with students who struggle, and teach in a multitude of ways to promote student understanding (Ashton & Webb, 1986; Pajares, 1996; Tschannen-Moran et al.). Although the Non-proficient Group and the Proficient Group teachers had significantly different student EOI scores, the PSTE scores were similar. This indicated a lack of relationship between PSTE and EOI Biology I scores.

This result was also supported by the finding that, although the 30 teachers who reported teaching AP Biology — in addition to teaching Biology I — had significantly higher PSTE scores than the 164 teachers who reported not teaching AP biology, there was no significant difference in the mean student EOI Biology I test scores between the two groups. It would be easy to assume that due to the extra training in content and pedagogical knowledge, AP biology teachers should have more confidence and a higher belief in their ability to teach than a teacher who had no AP training and teaching experience (College Board, 2000). In fact, in his State of the Union address on January 31, 2006, President George W. Bush called for the training of 70,000 high school teachers over five years for Advanced Placement science and math courses through the President's Advanced Placement Incentive Program (Bush, 2006). But despite this extra training and resulting higher PSTE scores, students of AP Biology teachers did not score significantly higher on the EOI Biology I test than students taught by teachers who had not experienced the AP training. This finding contradicts the findings of Goldhaber (2002) and Edie, Goldhaber, and Brewer (2004), who recognized that a teacher's knowledge of his/her subject matter was associated with high student performance, especially in the areas of mathematics and science. Thus, according to Goldhaber, teachers trained in AP biology should have higher PSTE scores due to their increased content and pedagogical knowledge which should result in increased student EOI Biology I scores.

This study also found that PSTE was positively correlated with three variables on the Teacher Attribute Questionnaire. First, although this study did not find correlations between PSTE and number of years in the teaching profession or number of years specifically teaching high school Biology, this study did find that as the age of the teacher increased so did the PSTE. Darling-Hammond (1999) and Goldhaber (2002) found evidence to support the belief that experienced teachers (usually teachers associated with increased age) were more effective with students than entry level teachers (teachers new to the teaching profession). However, the benefits of additional years of experience appeared to level off early in a teacher's career, about five years, unless a teacher chose to make conscious improvements or modifications in their learning and teaching.

The level of advanced college degrees was also positively correlated with PSTE scores. Darling-Hammond, Wise, and Klein (1995) concluded that teachers with more education were more effective in the classroom and teachers with advanced degrees were able to provide higher quality instruction. An advanced college degree, especially if the degree includes both content and pedagogical knowledge, as opposed to content knowledge only, provides teachers with the competency to create and adapt instructional strategies to

meet student needs (Good & Brophy, 1991).

Finally, teachers who felt his/her students were prepared to take the EOI Biology I test reported significantly higher PSTE scores than teachers who felt their students were not prepared. Bandura (1986) and Gibson and Dembo (1984) proposed that a teacher with high PSTE believes he/she has the abilities to perform the necessary tasks to bring about positive student change. Ashton and Webb (1986) reported that high efficacy teachers maintain high academic standards, have clear expectations, concentrate on academic instruction, and maintain students' standards.

In contrast to earlier research findings (Gibson & Dembo, 1984; Riggs & Enochs, 1990; Tschannen-Moran et al.,1998), this study found that high PSTE was not associated with increased student achievement as measured by End-of-Instruction Biology I scores. Reflecting on Bandura's social cognitive theory, how people interpret the results of their own behavior should inform and alter their environments and the personal factors they possess, which in turn, informs and alters subsequent behavior (Bandura, 1986). This is the foundation of Bandura's conception of reciprocal determinism. Thus, if teachers had received high student scores on previous EOI Biology I tests, belief in their ability to successfully teach Biology would be high, and they would continue to teach biology with confidence. On the other hand, teachers whose students had successively received low scores on EOI Biology tests may earn the belief that their knowledge of biology and how to teach biology were inadequate. At the time this study was conducted, the EOI Biology I test had only been administered to students for three years. Teachers may still be adjusting their content knowledge and teaching strategies to meet the new demands and expectations of this high-stakes test. Possibly, when teachers learn more of the EOI tests expectations, PSTE will be a better predictor of EOI Biology I scores.

Science Teaching Outcome Expectancy (STOE): The findings in this study suggest that End-of-Instruction Biology I test scores were significantly related to the expectations that a Biology teacher held for his/her students to learn biology regardless of student home environment, availability of classroom materials, or student motivation. From previous research findings, teachers with high outcome expectancy assume much of the responsibility for student learning instead of shifting the responsibility onto the student (Berman & McLaughlin, 1977; Gibson & Dembo, 1984; Riggs & Enochs, 1990; Tschannen-Moran & Hoy, 2001). By accepting responsibility for student learning, teachers demonstrate behaviors conducive to increases in student learning. Gibson and Dembo identified through classroom observation data that teacher efficacy may influence certain patterns of classroom behavior known to yield achievement gains. For example, teachers, who expect students to learn provide less criticism to students and persist with students until they respond correctly rather than going on to another student or another question. These teachers also communicate clear expectations to students while maintaining on-task behaviors and high academic standards for all students (Allinder, 1995; Ashton & Webb, 1986; Gibson & Dembo). These behaviors, when applied to Biology teachers, may find teachers with high STOE engaging students in inquiry activities, presenting materials for whole class discussions and developing alternative teaching strategies. These characteristics differ from teachers with low STOE who may use the textbook as the driving force behind the curriculum, provide numerous worksheets where students work independently, or engage students in small group discussions independent of other group interaction (Allinder; Gibson & Dembo).

Two variables obtained from the Teacher Attribute Questionnaire were significantly related to teachers' outcome expectancy score. Teachers who taught AP biology in addition to teaching Biology I showed a significantly higher outcome expectancy score than teachers who did not report teaching AP biology. Also, teachers who felt their students were prepared to take the EOI Biology I test reported a significantly higher outcome expectancy score than teachers who stated their students were not prepared.

Concluding Comments

The conclusions of this study foster a better understanding of the science teaching efficacy and outcome expectancy beliefs of Biology teachers whose students took the EOI Biology I test, in fulfillment of the NCLB Act. Data analysis yielded that the beliefs in the expectations that a biology teacher holds for his/her students to learn biology, regardless of student home environment, availability of classroom materials, or student motivation, was significantly related to high EOI Biology I test scores.

With an emphasis on quality teaching and high stakes testing as a measure of student achievement, a better understanding of the characteristics that deem a

teacher as 'highly qualified' need to be explored. Therefore, if the EOI Biology I test measures what it claims to measure, then teacher characteristics that have warranted salary increases are questioned. Traditionally, teachers have received a stipend or an increase in salary for additional years in the teaching profession, advanced degrees, attending professional development workshops, and attaining national board certification. In this study, none of these variables were significantly related to student EOI Biology I test scores.

Caution needs to be made in assuming that just because students do not achieve at the proficient level on standardized tests, learning is not taking place in the classroom. Researchers have demonstrated over and over again that AP Biology teachers and national board certified teachers have had significant gains in student academic achievement. One quantitative instrument should not be used to determine the quality of the teacher or the academic gains of the student. Therefore, further research needs to be conducted on the affects that a teacher's PSTE and STOE have on the results of student scores on the End-of-Instruction Biology I test. Recommendations for further research based on findings from this study lead to the following possible explorations:

- Longitudinal studies should be conducted to determine whether PSTE and STOE change as a teacher pursues national certification or AP certification. This may determine if teachers with high PSTE and STOE pursue additional certifications or if the certification process increases a teacher's PSTE or STOE.
- Additional studies should be conducted to further explore relationships between EOI test scores and socio-economic status/poverty rate of students enrolled in a school or district.

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The Flow Lab: A Simple Activity for Generating NOS Principles

While there is near universal agreement within the science education community that a strong understanding of nature of science (NOS) – both as a student goal and a teacher attribute - is critical, we still struggle with how to achieve these aims. Barriers range from pragmatic logistics to fundamental curricular tensions. In this paper, we share a classroom activity designed to aid in the learning of key NOS principles that we have found constructive. We discuss the basic activity, connections to science studies literature, and opportunities for explicit reflection on nature of science.

The Problem of Nature of Science

While there is near universal agreement within the science education community that a strong understanding of nature of science (NOS) – both as a student goal and a teacher attribute – is critical, we still struggle with how to achieve these aims. Barriers range from pragmatic logistics to fundamental curricular tensions. In this paper, we share a classroom activity designed to aid in the learning of key NOS principles that we have found constructive in overcoming such barriers.

Principles of the Nature of Science

Researchers in science education have settled on several tenets that depict nature of science (NOS) (Abd-El-Khalick, 2002; Abd-El-Khalick, Bell, & Lederman, 1998; Akerson, Abd-El-Khalick, & Lederman, 2000; Lederman, 1992; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). These general aspects of NOS are that scientific knowledge is tentative (subject to change), empirically-based (based on and/or derived from observations of the natural world), subjective (theory-laden), necessarily involves human inference, imagination, and creativity (involves the invention of explanations), and is socially and culturally embedded. Many of the national reform efforts have called for the infusion of understandings of nature of science in science education (American Association for the Advancement of Science, 1993; National Research Council [NRC], 1996). Science educators have tried both implicit and explicit approaches to incorporate NOS into their courses (Abd-El-Khalick; Akerson et al.) with mixed results. Furthering NOS understandings among teachers and students remains a challenge.

Approaches and Problems in Developing NOS

Recent research has focused on distinguishing between historical, implicit and explicit approaches in teaching NOS (Khishfe & Abd-El-Khalick, 2002). Historical approaches, utilizing case studies as a means of exposing students to the nature of science, have had a wide-ranging record (Solomon, Duveen, & Scot, 1992). Implicit approaches engage students in inquiry based activity (e.g., engaging the learners in asking scientifically oriented questions, collecting and using evidence to address these questions, formulating explanations and evaluating them in light of alternatives, and communicating and justifying their proposed explanations (NRC, 1996)) with the intention that by doing science, students will gain an understanding of nature of science. Some have criticized this approach for taking understanding of NOS as an affective attribute rather than cognitive outcome, and therefore argued for explicit discussion of NOS principles. Approaches including explicit instruction (intentional reflection on scientific work) have shown to be more effective (Khishfe & Abd-El-Khalick).

Including explicit instruction is not straight forward, however. It suggests the need for significant experiences in creating scientific knowledge that students can explicitly reflect on. Ironically, the greater challenge to science educators now might be not how to make explicit that which students experience implicitly, but rather how to make implicit that which we want to discuss with students explicitly.

In the logistical realm, time and materials are often barriers. At the systemic level, misperceptions about inquiry, pressures of accountability for content coverage, and beliefs centering around the appropriateness of teaching science as it's practiced in school science (Avery, 2003; Cunningham, 1995) also impede the implementation of inquiry-based science in classrooms. At the curricular level, inquiry-based activities that are both complex enough to demonstrate NOS principles and accessible are difficult to design and implement.

The difficulty in designing activities to demonstrate NOS principles can be summarized by considering two balancing acts.[1] The problem space – particularly the data participants will utilize – can range from simple to complex. If the problem space is too simple, the activity becomes a confirmation lab; if it is too complex, it becomes undoable in the classroom. Likewise, the particular assignment or charge given to participants can vary from very specified to completely open-ended. Too specified an assignment will be a traditional cookbook lab; too open-ended an assignment will leave students not knowing where to go. We have found utility in an activity – the flow lab - that addresses the issues surrounding implementing inquiry as well as those related to curricula design (Meyer, Antink, Knabb, & Connell, 2009; Meyer & Avery, 2007).

The Flow Lab

We first present the barebones Flow Lab activity, and then discuss how it might be implemented.

The Basic Activity

The Flow Lab activity originated as an activity for modeling the dynamics of a water tower (Carlsen & Trautmann, 2004). The basic activity uses the following simple apparatus: The bottom of an empty plastic bottle (e.g., 1 liter soda bottle) is cut off, and a small hole is drilled in the cap. The bottle is held upside down on a ring stand. A known amount of water is poured into the bottle while the hole is held shut. The hole is then released for ten seconds, and the amount of water that flows out is measured. Students are then instructed to experiment with different starting volumes in order to gain an understanding of the relationship between starting volume and collected volume. They are told that they will be challenged to predict the outflow volume for a new starting volume.

What appears to be a straightforward (and somewhat traditional) lab activity then generates experiences around key NOS activities. We will discuss these by dividing the experience into three phases: data collection, data analysis and sharing, and explicit reflection.

Data Collection

Participants are immediately faced with a situation not experienced in traditional "cookbook" lab exercises: while they have been given the basic protocol for measurement, they must establish the specific implementation to acquire the necessary data. More specifically, they must make decisions such as the number, range and distribution of test points. There is no external authority directing these choices. However, neither are the participants working in a vacuum, where anything is equally valid. They have the pressure of an explicit challenge: effectively predict the outflow for a starting value they have not tried. This will motivate their argumentation and resolution on what test range to use.

Besides the data range, participants flesh out other details of the procedures. Routines will be established such as who does what tasks, how timing is coordinated, etc. These are not necessarily conscious decisions, but rather represent the development of tacit skills around this research agenda.

At some point, participants will need to grapple with the occurrence of potential anomalies. Results will occur that vary from the participants' expectations. They will then have to decide how to respond: should it be rejected as an anomaly? Should the trial be repeated? As discussed below, there is no external arbiter.

For this portion of the activity, the instructor's role is as a facilitator, and a fairly passive one. For many questions participants pose, the instructor can refer back to the basic challenge, and impress on them the need for the group to make choices in light of that challenge. For example, when participants ask how many data points are necessary, the instructor can say that that is up to them, as long as they meet the challenge of being able to predict the outflow. The common "did we do it right?" can be met by inviting them to share their work.

Data Analysis and Sharing

Analysis of the resulting data can proceed in two phases: within the group for the purpose of addressing the challenge and sharing between groups. Appendix I illustrates examples of participant data.[2] As we discuss below, the variety seen in the data sets is crucial to this NOS experience.

As with the previous section, participants will often

behave in the mode of doing a traditional lab – they will often ask if their results are correct. The instructor can turn participants' focus first to the general question of conclusions about the relationship between starting volume and outflow, and then to the specific challenge of predicting an outflow. Since these two questions are in essence the same question – making a prediction requires a general conclusion about the relationship – the instructor can move back and forth between the two to respond to different participant reactions. For example, some participants may be reluctant to make a general conclusion, or simply be unused to being asked such an open question. The instructor can therefore shift to asking the group how they would go about making a prediction. This might prompt participants to identify a best-fit curve as the tool they would use, which essentially reifies their general conclusion.

Alternatively, the instructor can also ask specific questions about trends, outliers, etc. in order to bring them to the participants' attention. For example, with Data Set 5, participants could be queried about the data point at a starting volume of 500ml. (Note that the two circled data points did not exist during this initial analysis.) Is this point an outlier? Is the phenomenon following a smooth curve? The ambiguous nature of the data means that the resulting discussions around these questions are not trivial, but represent genuine scientific argumentation.

The choice of what specific starting volume to give to each group for which to make a prediction can be used in a very calculated way, prompting certain deliberations on the part of participants that they might otherwise avoid. For example, again with Data Set 5, giving a challenge of predicting the out flow with a starting volume of 525ml was used as a way of forcing a conclusion about whether the 500ml data point was an outlier and if the phenomenon was following a smooth curve. Questioning the scope of conclusions is another common issue that can be raised at this point. In Data Set 2, the participants were given a challenge point outside the general range of their data. In addition, this forced consideration of whether or not the curve was asymptotic or divergent.

Beyond analysis within one data set, comparing data between groups can raise additional issues, and lead to additional debates. Having groups use different bottle types and different hole sizes helps insure this variation. While some data sets might appear quite linear, others will display more of a logarithmic curve. Others still will exhibit some plateau phenomena.

Sharing data sets in the order they are shown in the Appendix is an example of how the instructor can intentionally foster critical debate. (These data sets were generated by students in a science teaching methods course.) An issue that arose in some groups but not others was whether there was a plateau phenomenon. Therefore, when Data Sets 1 and 2 were shared, those groups considered any slight dips as anomalies, and this position was supported by the class as a whole. However, when Data Set 3 was presented, that group considered the dip to be real, and argued as much. As additional data sets were shared, this position grew in acceptance.

As arguments for various conclusions are made, participants will also make restrictions on their claims in order to gain more acceptance. In particular, arguments will be made that Data Sets such as 1 and 3 are not in contradiction, but rather represent two different areas of the phenomenon. Besides the plateau question, the long-range nature of the phenomenon (asymptotic, linear, logarithmic) is another common point of dispute. Participants will often make reference to external theories, such as arguing that there is a limit to how much water molecules can be compressed.

Participants will also make references to the differences in bottles, hole size and data ranges. They will suggest, or the instructor can probe for, possible follow-up experimentation to clarify some of the ambiguity caused by the differences. This variation in experimental setup might seem like a poor experimental design – and to some extent it is. However, by having the problems emerge in this manner the importance of holding variables constant becomes apparent, and not an isolated mandate by the teacher authority.

Explicit Reflection

After deliberation over the flow data itself, discussion can turn to more explicit, reflective consideration of what happened. Thus, this activity provides the opportunity to make explicit students' implicit experience of NOS concepts and make personal their academic study of NOS concepts. We will discuss this through two organizational structures. First, we will make connections between the lab activities and readings and concepts taken directly from social studies of science. We have included in Table 1 information on some readings we have used. Second, we will match the activity to what has become the standard listing of tenets of nature of science in the science education community.

Science Studies Perspectives

The most significant concept generated by the Flow Lab activity is the occurrence of interpretive flexibility. The data that is generated, both within a single group and between groups, is ambiguous enough that multiple conclusions are possible (and arguable). The need to adopt a position is driven by the challenge to make a prediction. This phenomena mirrors the research in gravitational waves reported by Collins (1975, 1985) and neutrino detection reported by Pinch (1981, 1985). In these cases, the science community needed to grapple with new, surprising data that conflicted with contemporary theory.

Interpretive flexibility is tightly connected with the concept of experimenter's regress (Collins, 1985): when a new phenomenon is being studied, no external arbiter exists to distinguish whether unexpected results are due to a mistake in the theory the prediction is based on or a flaw in experimental technique. This is precisely the position participants find themselves in (and never do in confirmation labs). A surprising data point may be anomalous, or may be revealing the trend they are trying to find.

This interpretive flexibility in turn prompts significant argumentation and negotiation among the participants around different scientific conclusions. Reflective discussion can then be used to explore all the nuances of that process: how restrictions are added or removed from claims in an effort to make them more acceptable (Latour & Woolgar, 1986); how outside references are utilized (Latour, 1987; Toulmin, 1964); how presentation can affect audience response (Collins, 1975; Tufte, 1997). This can all be viewed as part of the broad process of social construction of knowledge and provides a way out of the experimenter's regress. In particular, a contrast can be shown between groups' comparative lack of confidence when only looking at their own data, and how that confidence increases as they interact with other groups with similar data patterns. This reflects the process of closure described by Collins (1981) and numerous other sociologists (see for example Bijker, 1987; Cowan, 1987; Kline & Pinch, 1996; Latour & Woolgar) where interaction facilitates resolution of analysis questions by the community.

While taken for granted during the activity itself, the concept of a black box – a conceptual or physical tool that is utilized without any challenge to its validity – can be explicitly discussed afterwards. Participants both make significant use of pre-existing black boxes (e.g. graduated cylinders, the concept of a line of best fit) and black box new concepts during the course of the activity (e.g. routines for running trials, "plateauing" as a reference to the data flattening out for a range). Furthermore, it can be pointed out how in the face of disputes, some areas of the experimental process were more likely to be questioned than others. This is comparable to Pinch's (1985) description of when data depends on a network of inference, there are multiple points to attack. Competing researchers look for the weakest points in the inference chain to attack data results.

Finally, the participants' work can be seen as occurring within a preexisting framework or paradigm. They have a degree of expectation about the results that at the very least includes it being a continuous function that generally increases and never decreases as the input is increased, and in some cases is restricted to a linear relationship. Adherence to a paradigm can be seen in participants' conclusions and arguments, just as described by Kuhn (1970).

Science Education NOS Tenets

The Flow Lab activity also provides predictable opportunities to address what have become the central tenets of NOS instruction in the science education community (Lederman et al., 2002).

Subjectivity. The exercise is at its core an experience of subjectivity. While they might ultimately reach agreement, participants will have clear disagreements over the interpretation of data. Consider, for example, Data Set 4. These participants had to judge whether to consider the data point around [240ml,26ml] as an outlier - including it resulted in one type of relationship; excluding it another. Deliberately giving the group the challenge value of 225ml helped to both force and highlight this decision.

Tentativeness. The subjectivity will lead to clear tentativeness. Participants (with the encouragement of the instructor if necessary) will place limits on the extent of their claims. Views will change as new data – such as data from other groups – becomes available, and participants can envision the impact of more focused follow-up experiments. For example, this class' view on the general pattern changed as they viewed the data sets in sequence. After viewing Data Set 1 and 2, the class was inclined to reject the inflection point pattern in Data Set 3 as either an anomaly or an oddity particular to that bottle. After viewing the remaining sets, however, they were more likely to view it as indicating a real phenomenon.

Empirical nature. While there will be variety in participants' interpretations, they are not arbitrary. Every claim that is made – even one in conflict with each other – is based on the empirical data. In fact, the subjectivity and tentativeness, as just described, is seen as directly arising from the data. Participants do not speculate arbitrarily about the phenomena, but rather are engaged over tangible data. For example, participants will make arguments both for and against there being an inflection point in the phenomenon. The data sets shown here provided support for both sides.

Creativity. Participants must use creativity to complete their assigned task. While they have the rudimentary parts, they must fill in details of their procedure. They must determine roles and procedures to do the practical work of data generation. While each groups' will be different, they will also be distinct, and are easily articulated on reflection. Once they have generated data, interpreting the data is not a straightforward, deterministic process. This lack of clear-cut procedure is continued when participants grapple with multiple data sets.

Observation vs. Inference. As an activity that has data interpretation and extrapolation as its core, the opportunity arises to discuss observations versus inferences. Participants can reflect on the various claims and arguments that they have made, and determine to what extent they were observations or inferences. For example, in data set 3, the plotted points represent more direct observations of the phenomena. By contrast, the sketched curves represent two inferences based on those observations.

Laws vs. Theories. One feature of this lab that lends itself to a variety of class settings is that it does not depend on a specific knowledge domain. In fact, students are generally discouraged from relying on external frameworks so that they focus on the empirical data rather than look for a "correct" result. The extent to which their claims and arguments do resort to prior knowledge can often be used to highlight the difference between laws and theories. Claims about the trend in the starting volume to flow relationship are akin to laws, whereas claims about the *cause* of the trend relate to theories.

Socially embededness. Lastly, while the activity might appear an isolated activity, connections to a greater community can be made. Participants may explicitly or implicitly utilize existing frameworks to argue for their claims. This would include seemingly mundane acts like viewing data through the lens of common mathematical curves. Reflecting on participants' expectations – e.g. an increasing function, a line of best fit - can highlight this.

Instructor Role

While we present this activity as one inherently rich in NOS principles, we also want to emphasize the importance of the instructor in maximizing the activity's benefit. It takes an instructor who, besides having a strong understanding of NOS themselves, has a keen sense of how and when to interact with students in order to positively affect their experience. This is an instance where the traditional student centered vs. teacher centered dichotomy is insufficient, and even counter productive. We agree whole heartedly with the spirit of student centered learning in so far as students must be engaged in substantive, active work, and teachers must avoid being sources of simple, unchallengeable information. But this does not mean that students should be placed on auto-pilot with a hands-off policy on the part of teachers. In addition, given that intervening too overtly and dominantly is the overwhelming tendency for teachers, perhaps we should consider waiting and holding back as an active move on the teacher's part.

Discussion

Spectrum of Implementation

Our development and reporting of this approach is based on utilizing the activity in a variety of settings over multiple iterations. It has served as the introduction to nature of science in elementary and secondary methods and curriculum design classes. It has also been incorporated into science content classes. We used it as a workshop activity for inservice science teachers and NSF GK12 graduate Fellows as well.

We have found that the basic activity is adjustable to participants' varying needs. For example, the context of modeling water towers is included with elementary teachers to provide purposefulness for the activity, while secondary science teachers tend to be more comfortable with a more abstract experiment. In general, the accessibility of the activity is a key element for overcoming elementary teachers' aversion to science whereas the ambiguity of the results is a key for breaking secondary science teachers preconceptions about lab activities.

Benefits

We see two major advantages to this approach. First, the activity provides a mechanism to essentially couple the historical, implicit and explicit approaches. Con-

cepts that can be explicitly discussed and illustrated through case studies are also made concrete through the students' experience. Second, the activity effectively achieves a balance point on the axes described above. The data generated are sufficiently complex and ambiguous to generate experiences of NOS principles. At the same time, the activity is relatively cheap, quick, and accessible to a wide range of students. The charge to students is both concrete and significant.

We see a number of additional appeals. The activity:

- Spans a number of science disciplines
- Provides an opportunity to model teacher practice in an inquiry setting (in the case of working with preservice and inservice teachers)
- Challenges assumptions about school lab dynamics
- Can be expanded in a variety of directions

The essential element in the activity is in the phenomenon itself, and the data it tends to generate. As can be seen in the example data sets, the Flow Lab will generate data that is sufficiently ambiguous that interesting discussion can occur. Providing students with an experience in which they participate in the process of making raw, ambiguous data into scientific conclusions requires access to interesting (i.e. messy) data. The Flow Lab's benefit is in providing predictably unpredictable results.

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Authors' Notes

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Keywords: inquiry, nature of science, professional development, teacher education

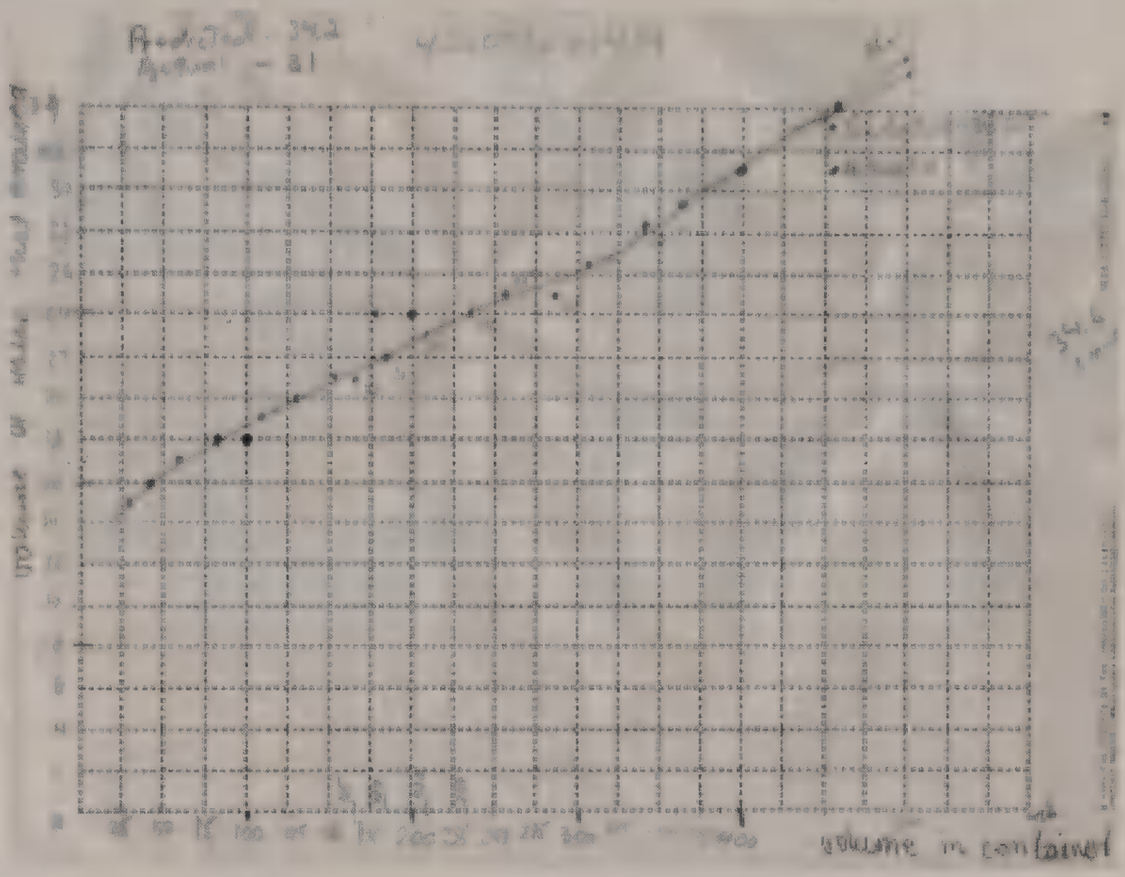
[1] This can be seen as a summary of the somewhat more general problem of designing inquiry based education.

[2] Note that these graphs include marks for each group's prediction and actual outcome from their challenge value, plus their original data set.

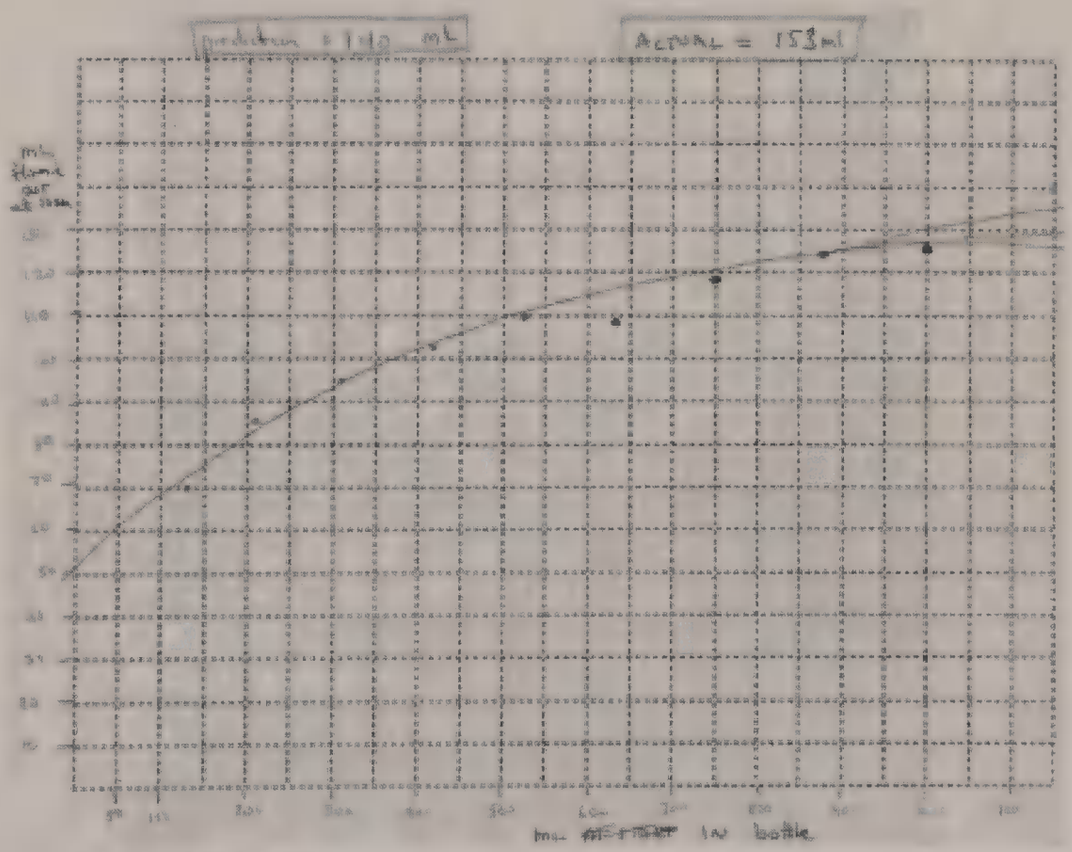
Appendix A

The following are examples of participants' data from the flow lab activity. The different groups used a variety of bottle types and hole sizes. In most diagrams, participants have also labeled their predicted outflow volume and actually outflow volume for the starting volume the instructor provided.

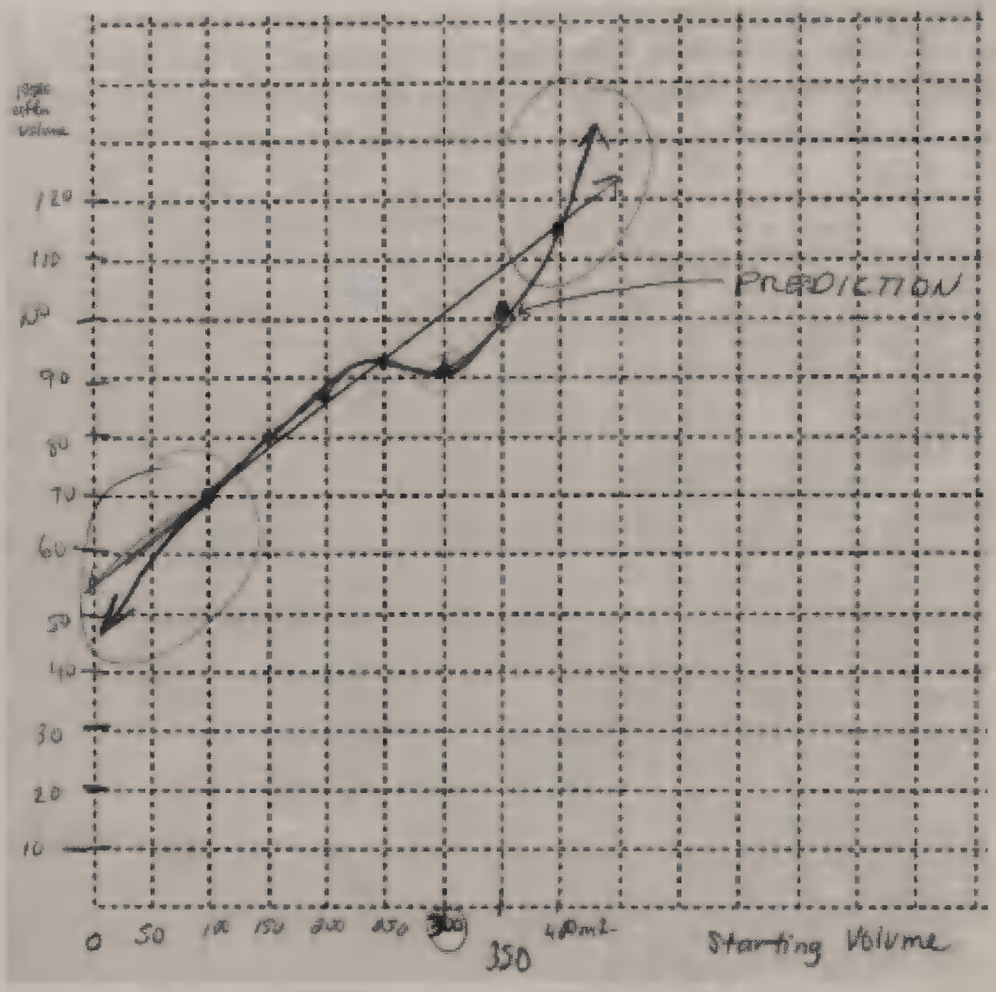
Data Set 1



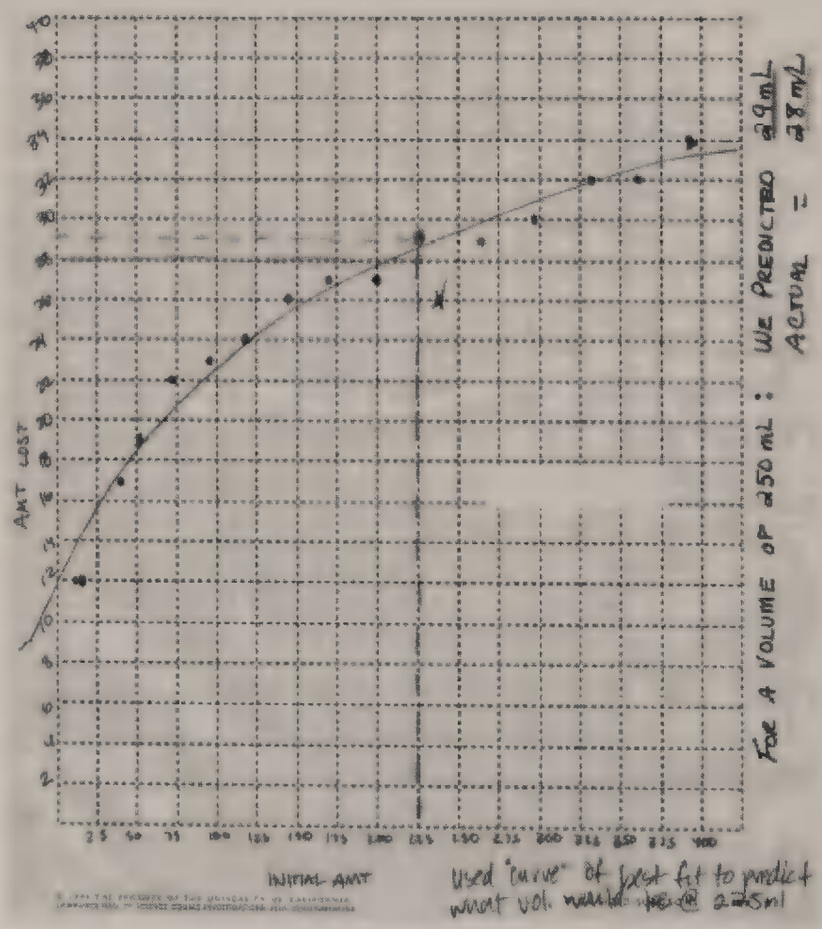
Data Set 2



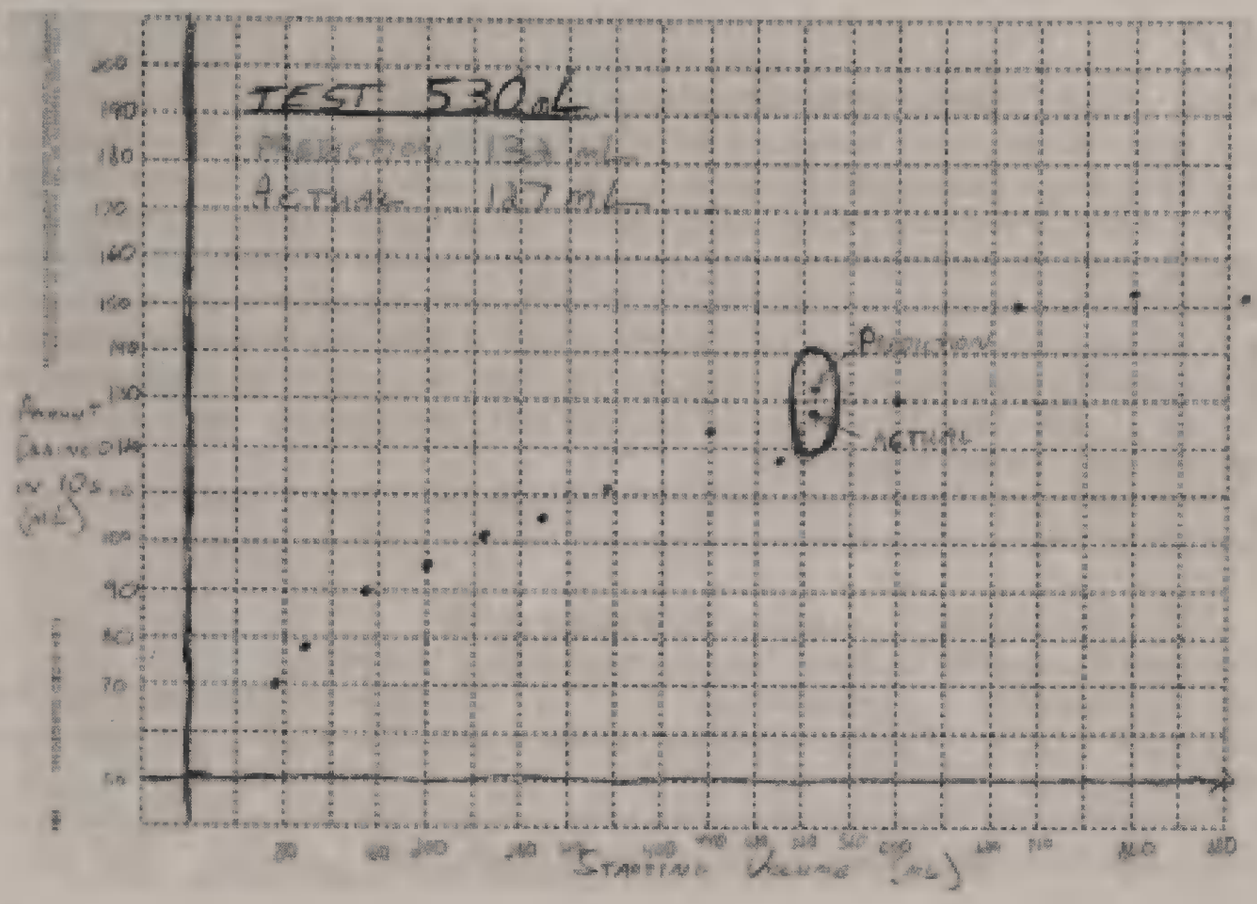
Data Set 3



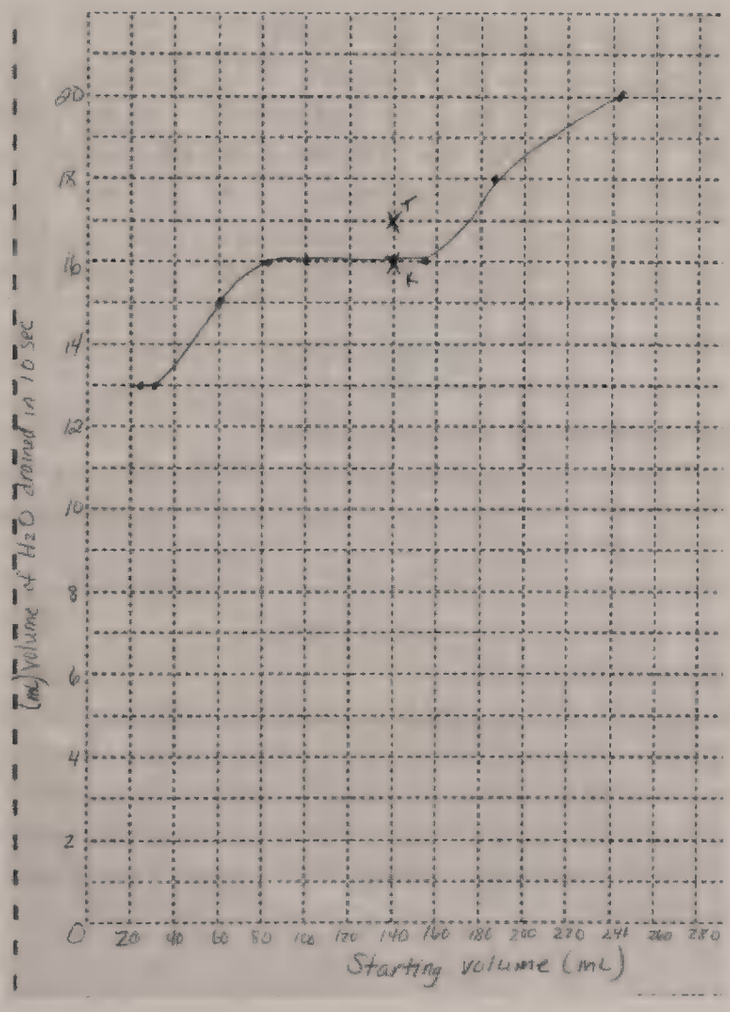
Data Set 4



Data Set 5



Data Set 6



Appendix B

Main References and Their Key Elements

Collins (1981); Collins (1985); Collins and Pinch (1998)

Concepts: Experimenters regress; Interpretive flexibility; Social interaction; Social construction

Overview: These three references detail the study of gravitational waves, specifically the controversy of Joseph Weber's claim to have detected high flux gravity waves, in contradiction to the prevailing theory of the time. Collins uses this case to illustrate the concept of experimenter's regress: either Weber had messed up in building his detector, or the detection was correct and the theory wrong. Determining which was the case requires knowing what the proper performance of a working gravitational wave detector. But knowing what the proper performance is requires knowing which case is correct. The 1981 citation is an original journal article, The 1985 citation is chapter from a book on the replication of data. The 1998 citation is a chapter from a general audience book on the formation of scientific knowledge.

Similar Phenomena in FL: Students will question whether their data is "right". Resolving this will depend on their negotiation. Debate within and between groups will mirror debate in the gravity case.

Latour and Woolgar (1986)

Concepts: Social construction; Claims → facts; Agonistic process; Inscriptions

Overview: This book details a participant-observer study of a microbiology lab. They frame their study as an anthropologist studying a tribe. They particularly focus on the process of how what begin as claims become accepted facts.

Similar Phenomena in FL: Claims will become solidified (or not) as their discussion progress. Conclusions will depend on social use of inscriptions. Argumentation will be important.

Latour (1987)

Concepts: Black boxes; Social construction; Claims → facts

Overview: The introduction to this book is a good overview of the (difficult) twist in thinking necessary to understand science studies. It begins with vignettes of DNA and computer use, both when each was the issue at hand and when each was an accepted tool for further use. The chapter challenges the typical assumption that determining the correctness of a conclusion leads straightforwardly from objective evidence.

Similar Phenomena in FL: Students will use various black boxes (graduated cylinders, watches) as will as black box routines on collecting data.; Conclusions will be accepted as a social process.

Kuhn (1970)

Concepts: Paradigms

Overview: This is the classic grand-daddy of science studies.

Similar Phenomena in FL: Students will enter the activity with (possibly varying) pre-existing frameworks that effect how they perceive the data. The typical set of mathematical relationships (linear, vs. logarithmic vs. exponential) is an example.

Pinch (1985)

Concepts: Black boxes; Argumentation

Overview: This paper details the study of neutron detection. It emphasizes the concept of black boxes – concepts, routines, devices, etc. whose internal details are accepted. It describes how what might seem like straightforward observations in fact depend on an apparatus of social accepted concepts and equipment. Furthermore, a critical way to challenge experimental results is to challenge an earlier link in the observational change.

Similar Phenomena in FL: Students will use a variety of black boxes (e.g. graduated cylinders, watches, routines for starting and stopping the flow).

Merton (1973)

Concepts: Norms of science

Overview: This is one of the first papers delineating the standard norms of science.

Similar Phenomena in FL: Students will employ the universality norm by assuming a generalizable answer (i.e. they will discount a particular bottle being too special).

Mitroff (1974)

Concepts: Norms and counter-norms

Overview: This is a sociological study of Apollo scientists and the emergence and documentation of the existence of counter-norms and the human side of scientific work.

Similar Phenomena in FL: Some challenges might hinge on evaluation of personal performance.

PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to: Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel; or fax to:972-86-477-648. Questions concerning proposals and/or solutions can be emailed to: eisenbt@013.net. Solutions to previously stated problems can be seen at: ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before February 15, 2010

5086: *Proposed by Kenneth Korbin, New York, NY*

Find the value of the sum

$$\frac{2}{3}+\frac{8}{9}+\cdots+\frac{2N^2}{3^N}.$$

5087: *Proposed by Kenneth Korbin, New York, NY*

Given positive integers a, b, c, and d such that $(a+b+c+d)^2 = 2(a^2+b^2+c^2+d^2)$ with $a<b<c<d$. Rationalize and simplify

$$\frac{\sqrt{x+y}-\sqrt{x}}{\sqrt{x+y}+\sqrt{x}} \text{ if } \begin{cases} x = bc+bd+cd, \text{ and} \\ y = ab+ac+ad \end{cases}$$

5088: *Proposed by Isabel Iriberri Díaz and José Luis Díaz-Barrero, Barcelona, Spain*

Let a, b be positive integers. Prove that

$$\frac{\ell(ab)}{\sqrt{\ell^2(a^2)+\ell^2(b^2)}} \le \frac{\sqrt{2}}{2},$$

where $\ell(n)$ is Euler's totient function.

5089: *Proposed by Panagiote Ligouras, Alberobello, Italy*

In $\triangle ABC$ let $AB=c, BC=a, CA=b, r=$ the in-radius and $r_a, r_b,$ and $r_c =$ the ex-radii, respectively.

Prove or disprove that

$$\frac{(r_a-r)(r_b+r_c)}{r_a r_c+rr_b}+\frac{(r_c-r)(r_a+r_b)}{r_c r_b+rr_a}+\frac{(r_b-r)(r_c+r_a)}{r_b r_a+rr_c} \ge 2\left(\frac{ab}{b^2+ca}+\frac{bc}{c^2+ab}+\frac{ca}{a^2+bc}\right).$$

5090: *Proposed by Mohsen Soltanifar (student), University of Saskatchewan, Canada*

Given a prime number p and a natural number n, calculate the number of elementary matrices $E_{n\times n}$ over field Z_p.

5091: *Proposed by Ovidiu Furdui, Cluj, Romania*

Let $k, p \geq 0$ be nonnegative integers. Evaluate the integral

$$\int_{-\pi/2}^{\pi/2} \frac{\sin^{2p} x}{1+\sin^{2k+1} x+\sqrt{1+\sin^{4k+2} x}}\,dx.$$

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